NAVAL POSTGRADUATE SCHOOL

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THESIS

GLOBAL POSITIONING SYSTEM DISASTER NOTIFICATION MESSAGING SERVICE

by

Alan C. Burwell

September 2013

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GLOBAL POSITIONING SYSTEM DISASTER NOTIFICATION MESSAGING SERVICE

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ABSTRACT

The United States has offered free worldwide position, navigation, and timing (PNT) broadcast data through the Global Positioning System (GPS) since its 1993 initial operations capable declaration, and periodic modernization efforts have been made throughout its 20-year history. A planned modernized L5 "safety of life" GPS signal, combined with the current GPS-enabled device ubiquity, offers an unprecedented opportunity to embed and broadcast other non-PNT information into GPS signals and reach individuals on a global scale with information in new ways. Adequate additional bandwidth exists in the new L5 "safety of life" signal to embed notification information for worldwide natural and technological disasters and add a new communication medium for a possible global disaster notification system. This thesis explores the background, requirements, system design and U.S. policy of a disaster-notification enabled GPS L5 "safety of life" signal.

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LIST OF ACRONYMS AND ABBREVIATIONS

AFWA	Air Force Weather Agency
BPSK	Bi-Phase Shift Key
CAP	Common Alerting Protocol
CDMA	Code Division Multiple Access
CMAS	Commercial Mobile Alert System
CRC	Cyclic Redundancy Check
CRED	Centre for Research on the Epidemiology of Disasters
DIR	DNMS Message Event Shape Direction Field
DNMS	Disaster Notification Messaging Service
DoDD	Department of Defense Directive
DSSS	Direct Sequence Spread Spectrum
DUR	DNMS Message Event Duration Field
EGNOS	European Geostationary Navigation Overlay Service
ETYPE	DNMS Message Event Type Field
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
FOC	Final Operations Capable
GDACS	Global Disaster Alert and Coordination System
GEO	Geosynchronous Earth Orbit
GPD	Gross Domestic Product
GPS	Global Positioning System
GPSW	Global Positioning System Wing
HFA	Hyogo Framework for Action

ICD	Interface Control Document
IOC	Initial Operations Capable
IPAWS	Integrated Public Alert and Warning System
JSpOC	Joint Space Operations Center
LKLI	DNMS Message Event Likelihood Field
LOC	DNMS Message Event Location Field
MCS	Master Control Station
MEO	Medium Earth Orbit
MSGID	DNMS Message Event Identification Field
NGA	National Geospatial-Intelligence Agency
NOAA	National Oceanic and Atmospheric Administration
NSS	National Security Strategy
PDOP	Position Dilution of Precision
PNT	Position Navigation and Timing
PPS	Precision Positioning Service
PREC	DNMS Message Event Precedence Field
PRN	Pseudo-Random Number
RAT	DNMS Message Event Shape Ratio Field
SAME	Specific Area Message Encoding
SATCOM	Satellite Communications
SBAS	Satellite Based Augmentation System
SEV	DNMS Message Event Severity Field
SHP	DNMS Message Event Shape Field
SIZ	DNMS Message Event Size Field
SMC	Space and Missiles Center

SMS	Short Message Service
SoL	Safety of Life
SOPS	Space Operations Squadron
SPS	Standard Positioning Service
TIM	DNMS Message Event Time Start Field
TXT	DNMS Message Event Text Field
WAAS	Wide Area Augmentation Service
WEA	Wireless Emergency Alert
WGS84	World Geodetic System 1984
XML	Extensible Markup Language

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First and foremost, I would like to thank my beautiful wife, Robyn Burwell, whose unyielding patience and support has allowed me to combat the tyranny of the urgent in this endeavor. I would also like to extend thanks and appreciation to my thesis advisor Daniel Bursch for his patience and optimism.

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I. INTRODUCTION

Throughout recorded history, natural and man-made disasters have killed and continue to kill millions. While some disasters strike with little warning, oftentimes there exists some element of prediction or warning; many disasters can be forecast hours, days or more in advance, or have durations which can be forecast days or months in advance. Earthquakes, volcanic eruptions, floods, tsunamis, blizzards, hurricanes, tornadoes, droughts, extreme temperatures, wildfires, epidemic outbreaks and radiation hazards all have some measure of predictability or have durations that can be exploited by warning systems for the betterment of society. While these disasters may be arguably beyond the scope of society to control, it is within society's control to alert those who would otherwise come to harm. With warning, individuals can act to save lives throughout all stages of disaster events.

Modern disaster notification systems are inherently localized at national levels, disaggregated, or require subscriptions to information feeds. Within the United States and other high gross domestic product (GDP) nations, significant work has been done to integrate and ensure warning information is received by all individuals, but the United Nations reports that there remains much work to be done, especially in countries with lower GDPs, which have significantly increased disaster mortality rates (United Nations Office for Disaster Risk Reduction, 2011). By approaching the problem differently and inserting disaster notification information into a worldwide broadcast system that a significant number of individuals already access data through, such as the Global Positioning System (GPS) data broadcast stream, disaster alert and notification data can be sent as persistent and free information to the world, automatically ingested in electronic devices already used by consumers. This analysis will theorize a feasible, low cost disaster notification system which can integrate the existing GPS space based architecture into existing aggregated notification systems, to provide a disaster notification service to the world.

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II. BACKGROUND

A. EXISTING DISASTER NOTIFICATION SYSTEMS

There currently exists a wide variety of systems intended to aggregate disaster information in order to streamline notification, response and recovery efforts. Commercially, in recent years there has also been an effort amongst organizations to utilize social networking systems to transmit disaster notification information to individuals through phone, SMS text, email, FaceBook, MySpace, Twitter and a myriad of other systems. In commercial systems, active participation is required through subscription or opt-in services in order to receive alert information.

Within the U.S. government under the Department of Homeland Security, the Integrated Public Alert and Warning System (IPAWS) has been developed to integrate into the Federal Emergency Management Agency (FEMA) framework and send information for imminent threats, presidential alerts, or AMBER alerts to the public (FEMA, 2013). Imminent threats include natural, accidental or man-made disasters. The IPAWS system is designed to disseminate alert and warning information through phone, radio, and TV, and is intended to be scalable with new and emerging technology. National, local or state officials can send authenticated messages tailored to specific areas through the IPAWS framework to reach individuals at the national, local or state levels, respectively.

IPAWS is also tied to the Commercial Mobile Alert System (CMAS) which can provide Wireless Emergency Alert (WEA) text messages through most mobile phone service providers (FEMA, 2013). Wireless providers representing approximately 97% of the U.S. population are active participants in disseminating WEAs (CTIA, 2013), though while the U.S. government mandated that all mobile phones will be compliant in 2012, "…not all phones and operating systems are capable of receiving [alerts]" (Fox 13 Staff, 2013). Phone software and hardware versions as well as wireless carrier systems affect the ability for users to receive messages. During Hurricane Sandy in October of 2012 when 24 U.S. States had lost power, displaced persons, or destroyed homes, Verizon-serviced iPhone 4S and 5 generation phones were unable to receive alerts; however, those same generation phones received alerts under AT&T service. Differing combinations of phone operating system types and versions (Android, iOS, Windows 8, Blackberry OS, et al.) service providers (AT&T, Alltel, Verizon, Sprint, et al.) and towers precluded some users from receiving alerts. FEMA reports that phone carriers and manufacturers will continue to voluntarily increase the number of supported devices. In cases where cell phone towers are overloaded with traffic, WEAs have priority and will still be delivered, though if power is lost at towers due to a disaster, no WEAs would be transmitted. Also, the CMAS system is inherently localized, as a service provided by the U.S. government for U.S. citizens.

Across international borders there are few truly global alert and notification options available. The United Nations in collaboration with the European Commission maintains the Global Disaster Alert and Coordination System (GDACS). The GDACS establishes partnerships with scientific monitoring organizations and aggregates worldwide disaster information during the first phase following a natural disaster. The primary users of GDACS, however, are governments and disaster response organizations. There is no direct system or process in place for individuals to receive GDACS alert information, though users have access to disaster information on the GDACS website. Several specific types of disasters have international organizations or frameworks established to aid in alert and notification, such as the Pacific Tsunami Warning Center hosted by the National Oceanic and Atmospheric Administration (NOAA), but these systems are generally not explicitly tied into international natural disaster warning systems, and are localized to an event type and geographic area.

The Hyogo Framework for Action (HFA) is a 10-year United Nations plan intending to explain, describe and detail required work from all different sectors and actors to reduce disaster losses. Priority 2 of this plan is to “Identify, assess and monitor disaster risks and enhance early warning” (Hyogo Framework for Action, 2011). Progress for all nations is periodically reported on; results from this report indicate that in some nations early warning systems are in place for all major hazards with outreach to communities, but in many nations only risk information and monitoring is available.

Disaster Risk Mitigation systems tend to be regionally focused and skewed toward stand-alone investments instead of integrated at the multi-national level.

Each notification system necessitates the use of a messaging format or protocol. Most United States systems rely on the standardized Common Alerting Protocol (CAP). The CAP was built upon the Extensible Markup Language (XML) framework to be simple, machine and human readable, straightforwardly implemented, support a wide variety of applications as well as to simultaneously disseminate alert and warning information over disparate warning systems. Within the United States, the Department of Homeland Security, the National Weather Service under the NOAA, the United States Geological Survey, and others, as well as many state and local governments utilize the CAP. Within the Department of Homeland Security, the CAP is the foundational technology for IPAWS as well as CMAS. The International Telecommunications Union (ITU) adopted the CAP specification in 2007 to lay the foundation for future international disaster alert information sharing. Canada and Australia have both developed and utilize localized variants of the CAP.

B. DISASTER STATISTICS

The Centre for Research on the Epidemiology of Disasters (CRED) at the School of Public Health of the Universite catholique de Louvain maintains a database of all natural disaster events that have occurred worldwide from 1900–2011 compiled from a variety of sources to include United Nations agencies, non-governmental agencies, insurance companies, research institutes, etc (CRED, 2011). A natural disaster must meet one of the following criteria in order to be considered: 10 or more people killed, 100 or more people affected, declaration of a state of emergency or a call for international assistance.

In general, the effects of natural disaster events change drastically with time and notification technology. As reporting systems evolve, the number of reported events worldwide continues to increase to approximately 400 annual events having occurred in 2011. As warning and notification systems advance, the number of persons killed continues to decrease to approximately 20,000 individuals in 2011, while the number of persons affected continues to increase to approximately 250,000,000 individuals in 2011. These trends can be seen in Figure 1, provided by CRED.

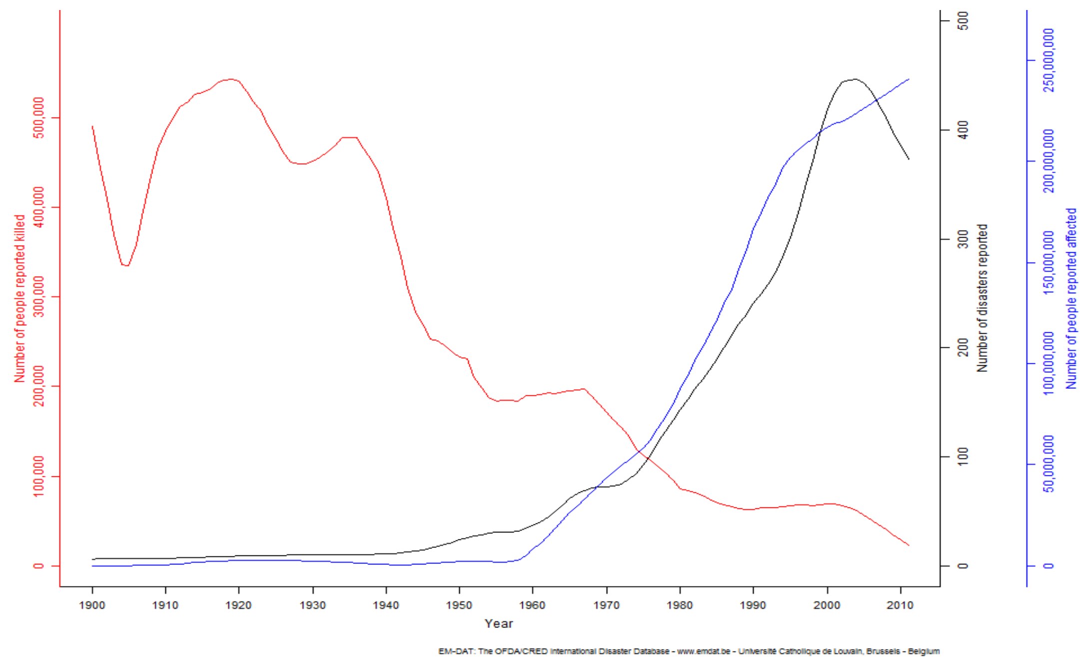

Figure 1. Natural Disaster Statistical Summary 1900–2011 (From CRED)

The maximum number of distinct natural disasters per year peaked in 2001 with approximately 450 events. Within a single country, some events last for hours, while other simultaneous events last for months. For instance, in Afghanistan in 2012, multiple brief earthquakes and an 8 month drought were experienced simultaneously. Detailed statistical analysis refined to a high fidelity timeframe of individual days and hours could not be found, so a preliminary analysis was performed on CRED disaster data from 2010 to present. The global average disaster event duration is approximately 22.2 days with a 1σ standard deviation of 58.9 days. Accounting for 0 to +3σ potential events (99.9% of all events) yields a potential event duration of 198.9 days. Using the maximum annual number of events from 1900–2010, averaged daily, there are approximately 1.23 events per day. Assuming an approximately even distribution of events throughout the year, this assumption yields approximately 244.6 simultaneous events occurring (not starting, but occurring with overlapping durations) world-wide per day, on average. A notification system must have capacity to account for 244.6 simultaneous natural disaster events in order to account for all disaster events with 99.9% certainty. The average number killed per natural disaster is 349 individuals, with a 1σ standard deviation of 7180 individuals. In calculating standard deviations in values above mean, a normal distribution is assumed; this assumption and the statistics involved in driving notification system requirements needs to be further refined.

Figure 2 shows the relative number and type of the most common and most impacting natural disaster events from 1900–2011, and is used as a baseline of event types in designing a natural disaster notification system.

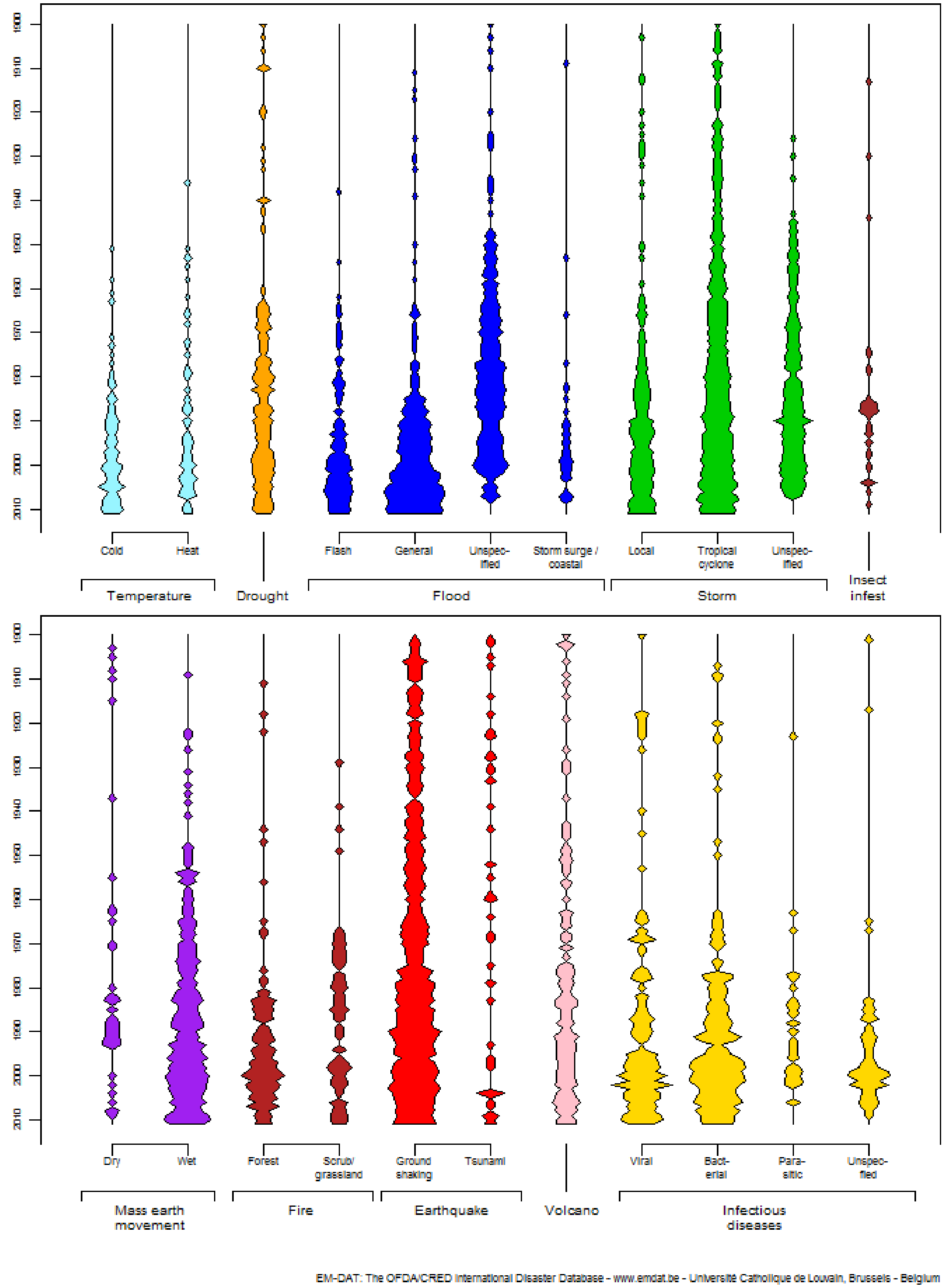

Figure 2. Reported Natural Disaster Event Types 1900–2011 (From CRED)

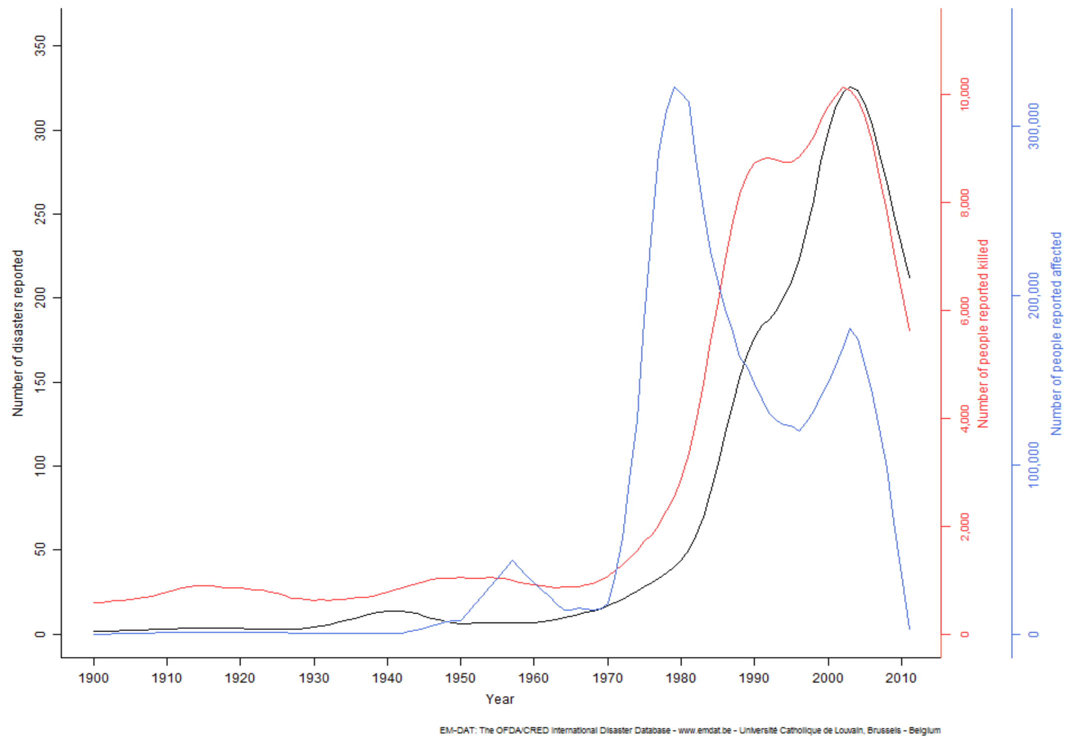

Figure 3. Technological Disaster Statistics 1900–2011 (From CRED)

The analysis accounts for only natural disasters, not those which are man-made; statistics accounting for all man-made disasters are not readily available. CRED reports disaster data for a subset of man-made events deemed technological disasters, including chemical or gas leaks, explosions, transportation accidents, et al., but many significant events such as genocide, armed conflict, terrorist attack, or other man-made events are not accounted for. Figure 3 shows technological disasters from 1900–2011. This includes data for events such as transportation accidents or some industrial accidents that have a duration or event start that cannot be forecast or would not be included in a disaster notification system; this analysis assumes that these man-made accidents are inconsequential to the total disaster event numbers which ultimately drive notification system requirements. Similar to natural disasters, technological and man-made disasters change significantly with advances in technology. The number of worldwide reported events, number of individuals killed and number of individuals affected increased significantly from 1970–2002, then dropped sharply to 2011 levels. The average disaster event duration is approximately 1.37 days with a 1σ standard deviation of 8.76 days.

Accounting for 0 to +3σ potential events (99.9% of all events) yields an event duration of 27.7 days. Using the 2011 annual number of events, averaged daily, there are approximately .55 events per day. Assuming an approximately even distribution of events throughout the year, this assumption yields approximately 15.1 simultaneous events occurring (not starting, but occurring with overlapping durations) per day, on average. A notification system must have capacity to account for 15.1 simultaneous technological disaster events. For the purposes of this analysis, it will be assumed that the number of man-made disaster events not included in the CRED technological disaster statistical analysis are inconsequential to the design of a disaster notification system. The average number killed per technological disaster is 30.8 individuals, with a 1σ of 53 individuals. The stated assumptions on standard deviation and statistics also apply.

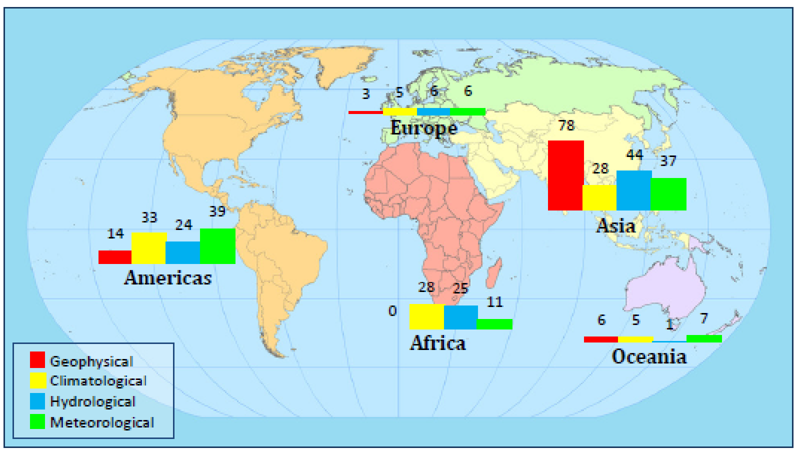

Figure 4. Natural Disaster Geographic Distribution 2011
(From Guha-Sapir et. al.)

Geographic distribution of natural disasters plays a critical role in understanding disaster event statistics and in ultimately deriving notification system requirements. Figure 4 shows the continental distribution of natural disasters by disaster type grouping in 2011, and it can be seen that events are approximately distributed East-West, interpreted to assume a relative global distribution. This figure does not provide detailed information on the relative sizes of events or their geographic distribution by size, and statistics are not readily available. It will be assumed that disaster events are approximately evenly distributed globally with a size up to global, but this assumption needs to be further refined.

In total, to capture 99.9% of natural and technological disasters, a disaster notification system would need to be capable of simultaneously processing 261 (244.8 natural and 15.1 technological) daily disasters. Two hundred sixty one events assumes that a notification system trigger and report on events using the same criteria as used in the CRED data, whereas realistically different criteria would be used such that the capacity of a notification system matches the real-world disaster events reportable by system's trigger criteria. The average number of individuals killed per event, for all event types reported by CRED is 251. Throughout this analysis of disaster events however, numerous assumptions were made regarding the numbers and distributions of time, duration, geographic location, size, type, etc. These assumptions and the statistical analysis should be further refined to develop requirements before implementing a world-wide disaster notification system.

C. GPS-ENABLED SMARTPHONE USE

In 2011, approximately 87% of the worldwide population owned or operated a mobile phone subscriber service. That same year, of the approximately 6 billion mobile phone users, 700 million used 'smart phones' with advanced computational capability. It is estimated that by 2017, of the forecast 9 billion mobile phone users, over 3 billion will use 'smart phones' (Mobithinking, 2013). Smart phone technology is continuing to grow at exponential rates and is becoming ubiquitous in all modern societies, offering unprecedented communication opportunities. In 2011, approximately 80% of smart phones were GPS enabled, with this percentage also continuing to trend upward exponentially (Rebello, 2010). In 2011, more than 560 million people can be reached near-instantly through the GPS signal via cell phones alone, and that number will continue to rise.

In addition to smart-phones, other electronic devices can utilize the GPS data stream. Laptops, tablets, hand-held video game devices and a variety of stand-alone navigation and other systems are increasingly GPS enabled. In many modern automobiles, GPS navigation is offered standard. Similar to cell phones, other electronic devices will increasingly continue to incorporate the GPS signal. It is assumed that those individuals with access to GPS data approximately represent the relative cross section of individuals affected by natural or technological disasters.

D. AN IDEAL WARNING SYSTEM

An ideal disaster notification system is generally considered to be a collection of systems both to aggregate source reportable events as well as transmit notification data through a variety of mediums in order to reach the maximum number of individuals in the shortest time period possible. These systems must utilize technology and information systems that are ubiquitous in the largest number of international societies reaching as many individuals as possible, potentially through a wide variety of information systems. The ideal information receiver would be integrated in some capacity with a device or information stream that individuals already voluntarily use as an information hub which has standalone power/battery capabilities. The system would need to be standardized in a way that allows competing manufacturers to create a variety of devices compatible with the system to drive materiel and manufacturing costs down. The system would also need to be responsive to multiple simultaneous disaster events with sufficient data throughput capacity to provide simultaneous notifications world-wide in near real-time, tailored to the location affected by the disaster. Additionally, the system needs to be feasibly and inexpensively implementable. Figure 5 depicts a generalized national level notification system in which local and regional event information filters up to higher level reporting and aggregation, as well as is transmitted using available means at each level, ultimately reaching the end user through a variety of means and mediums.

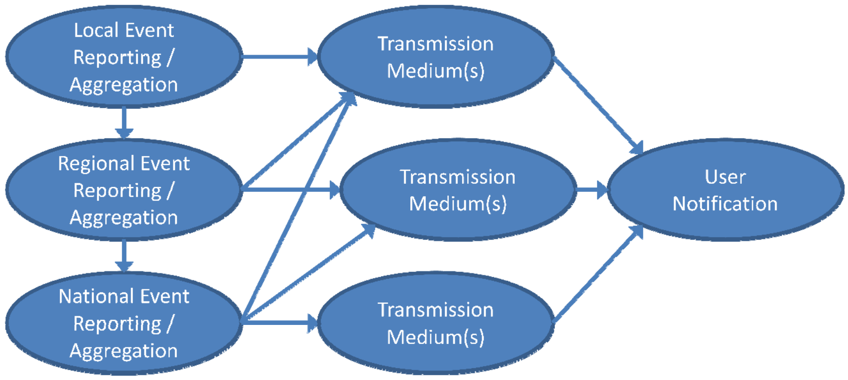

Figure 5. Generalized National Level Notification System

This generalized ideal system is functionally similar to the FEMA's IPAWS system in the United States, but can be applied more broadly to support international events and additional transmission means, as depicted in Figure 6. This modified generalized system would be comprised of reporting nodes at local, regional and national levels, aggregating nodes, international command and control, and a variety of transmission mediums. The reporting nodes require trusted communication to aggregating nodes which represent major worldwide geographical or functional areas. Aggregating nodes would send disaster information to a central command and control location which would utilize a variety of transmission mediums, potentially including those indigenous to unique areas.

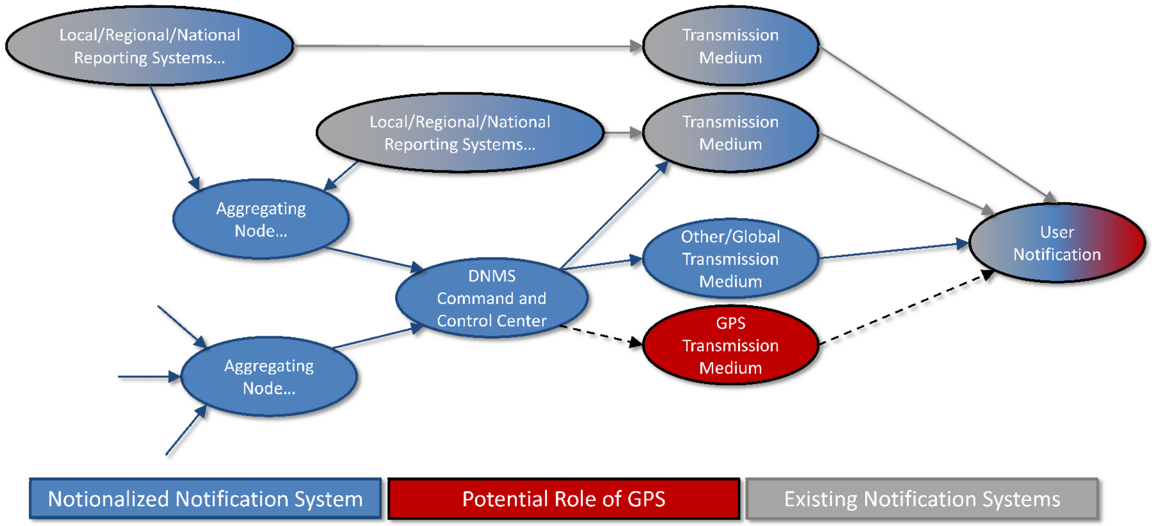

Figure 6. Generalized Expanded Notification System

This communication scheme would allow event reporting from local to international levels to be centrally transmitted through all available communication means for the affected local area(s). One component of this idealized system is the ability to transmit notification data to local, regional, national or arbitrarily defined geographic areas irrespective of national boundaries. Additionally, many of the terrestrial and consumer links in transmission mediums such as cell phone towers, data processing facilities, etc can be bypassed and information more directly transmitted to end users. There exists a unique and unprecedented opportunity to use the existing GPS architecture to transmit data to GPS-enabled smart phones and other GPS enabled devices and provide this transmission medium in order to reach a significant number of users world-wide. This system would trigger human and automated machine responses to save lives, and would permeate the earth to reach individuals potentially unreachable through other means. The approach to utilize the GPS architecture for disaster notification services analyzed here will henceforth be referred to as the GPS Disaster Notification Messaging Service (DNMS, pronounced '*din mis*'), and the factors to consider in implementing said system will be the focus of this analysis.

E. GPS BACKGROUND

1. System Overview

The GPS is a day or night, all weather radio broadcast based global navigation satellite system (GNSS), functionally broken into three disparate segments: the space segment consists of a constellation of medium earth orbit satellites and the transmitted GPS signals; the control segment consists of ground antennas, monitor stations and command and control nodes; the user segment consists of all users and systems in receipt of GPS signals.

The space segment by original design required a constellation size of 24 broadcast spacecraft split amongst 6 orbital planes, each at 55 degree inclination, separated by 60 degrees in geometric location of the ascending node. A medium earth semi-synchronous orbit was chosen such that the period exactly matches half of one sidereal day. As of November 2012, 30–31 healthy satellites simultaneously broadcast usable GPS data, exceeding the standard baseline. Due to a coding limitation with signal structure, on older legacy signals no more than 32 usable 'healthy' satellites can simultaneously exist. Each satellite continuously broadcasts a combination of its own clock and ephemeris data as well as orbit information for other satellites in the constellation; it is through this data that GPS position, navigation and timing (PNT) solutions can be acquired. With 32 healthy satellites, on average, 8–11 satellites are in view of any location on earth at any given time. Due to the constellation design utilizing trilateration to mitigate position dilution of precision (PDOP) uncertainty, terrestrial observers see the satellites always moving and generally dispersed throughout the sky. The combination of the number of spacecraft and their orbital geometry ultimately allow the constellation to be a reliable source of information at any time, for world-wide users.

The control segment is responsible for maintaining the health of the entire GPS. As of November 2012, the control segment had access to 4 indigenous ground antennas as well as 8 additional Air Force Satellite Control Network (AFSCN) antennas, all geographically separated. Ground antennas are responsible for 2 way C-Band command and control of GPS satellites, to include verification of telemetry, data uploads, as well as downloads of additional payload information (i.e., Nuclear Detonation Subsystem). In November 2012, the control segment had access to 6 indigenous monitor stations as well as 11 additional National Geo-Spatial Intelligence Agency (NGA) monitor stations, all geographically separated. Monitor stations are responsible for continuously receiving L-Band payload information and relaying data to the command and control nodes. The primary command and control node and 24/7 operations center, dubbed the Master Control Station (MCS), is located at Schriever AFB, CO. The alternate MCS is located at Vandenberg AFB, CA. The net effect of the control segment is that at any moment, every satellite's payload broadcast data is being monitored and any satellite can be contacted to be corrected or updated.

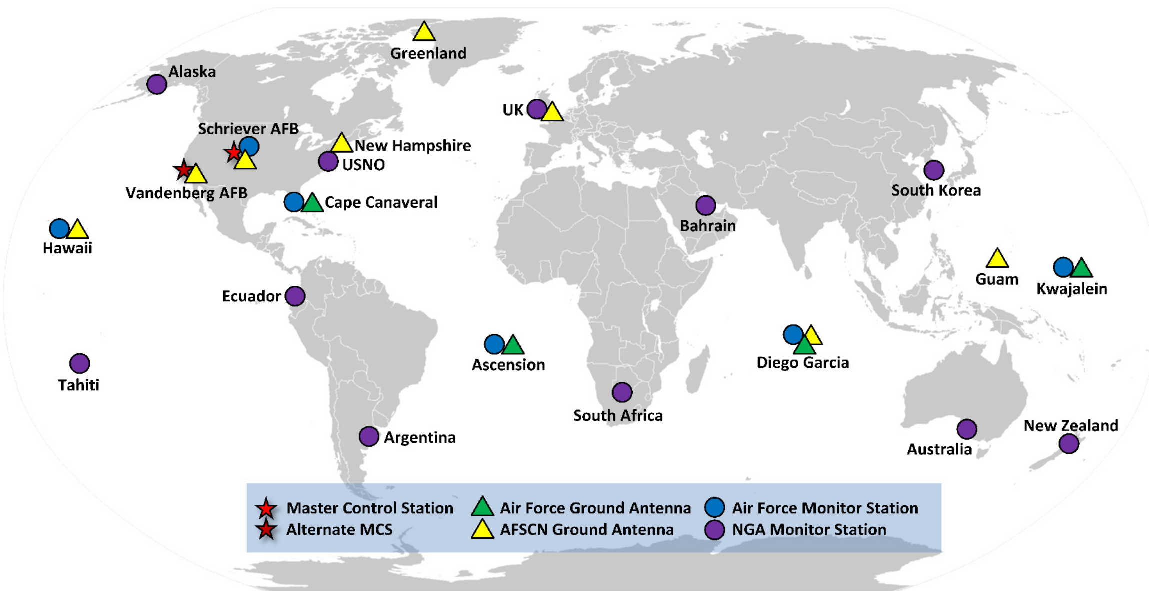

Figure 7. Control Segment Infrastructure

The user segment consists of all users, automated equipment and systems in receipt of any GPS signal. This includes military users as well as civilian users with diverse systems to include: military personnel and aircraft tracking and navigation, car navigation, banking financial transaction timing, farm equipment mapping and navigation, et al.

2. Signals and Modernization

The GPS was designed for the payload to operate in the L-band as a balance between atmospheric attenuation of higher frequencies and lower data-rate of lower frequencies. A circular polarization was chosen to mitigate the effects of Faraday rotation on polarity as the signals pass through the ionosphere. A Bi-Phase Shift Key (BPSK) direct sequence spread spectrum (DSSS) modulation scheme was chosen to allow significant processor integration gain in noisy signal environments without interfering with other systems and ultimately make the system robust against inadvertent interference. Each satellite transmits on the same base frequencies, but code division multiple access (CDMA) is used to differentiate and uniquely identify each satellite and individually process each satellite's data. Each vehicle broadcasts data modulated on a separate pseudo-random number (PRN) code, and by publicly publishing the PRN codes in a GPS interface control document (ICD), receiver equipment can be manufactured with PRN codes pre-defined in software and hardware in order to track each GPS satellite.

	Launch	**L1**				**L2**			**L5**
IIA	1990–1997	C/A	P(Y)			P(Y)			
IIR	1997–2004	C/A	P(Y)			P(Y)			
IIR-M	2005–2009	C/A	P(Y)			P(Y)	L2C*		
IIF	2010-Future	C/A	P(Y)		M*	P(Y)	L2C*	M*	SoL*
IIIA+*	Future	C/A*	P(Y)*	L1C*	M*	P(Y)*	L2C*	M*	SoL*
*Not broadcasting healthy PNT data or not yet launched									

Table 1. Current and Future GPS Broadcast Types

On the Block I, II, IIA and IIR GPS satellites launched through 2004, a legacy unencrypted standard positioning service (SPS) civilian course acquisition (C/A) code and a precision positioning service (PPS) encrypted military (P(Y)) code has been broadcast. The military P(Y) signal has lower peak power at the center frequency, but has 10 times the bandwidth increasing overall received energy, substantially increasing resistance to purposeful or inadvertent interference radiation.

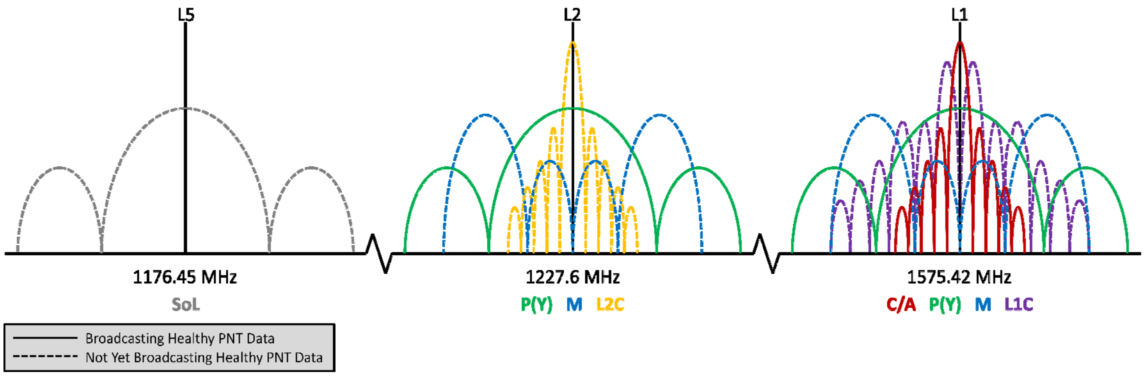

Figure 8. GPS Frequency and Broadcast Signals

Beginning in 2005 with the Block IIR-M satellites, each successive generation adds additional modernized signals, including L2C, M, and 'safety of life' (SoL) signals. The modernized signals allow the use of more than 32 healthy PRN codes, alleviating a layer of specificity in the legacy design, and also changed the data structure from strict bitwise definitions to a more flexible messaging structure. Though the modernized signals have existed on satellite vehicles, no healthy usable data is transmitted due to limitations in development of the control and user GPS segments.

	Healthy 2013	2015 Projection*	Total
IIA	9	5	28
IIR	12	11	12
IIR-M	7	7	8
IIF	3	6	12
III	0	2	32
*2015 assumes base-lined attrition of older vehicles			

Table 2. GPS Block Constellation Size (From Shaw)

The Block IIF first launched in 2010 and the future Block III satellites add a distinct new civilian SoL broadcast on an L5 signal. The L5 signal is located in an aeronautical navigation band with more protected frequency space than the L1 or L2 signals in order to mitigate interference. This new signal is also of a modernized flexible messaging structure, but similar to other modernized signals, no healthy usable data is currently available. Similar to the P(Y) broadcast, the L5 broadcast will have a significantly larger bandwidth (~10 times) that of the main lobe of C/A, L1C or L2C, but with identical data rate will therefore have higher processing gain and be less susceptible to inadvertent or intentional interference.

Any modernized civilian broadcasts can be considered for the DNMS, but given the protected nature of the frequency range in which the L5 SoL signal resides and the significant protection from interference through an increase in L5 bandwidth and processing gain, the L5 signal was chosen as the focus of the DNMS system.

Within a legacy or modernized, military or civilian signal, of 300 primary message bits, 24 are dedicated as cyclic redundancy check (CRC) bits acting as parity to ensure that the message is received as intended from the satellite. The probability that a received sub-frame or message contains a single bit error is approximately 1e-18, based on ICD-GPS-200E, and is assumed to be statistically irrelevant for the purposes of this analysis.

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III. GPS DNMS

The GPS DNMS is the theorized system in which disaster alert and notification information is embedded into existing available bandwidth of the L5 SoL GPS signal. As a system, DNMS includes the control segments and information links necessary for command and control of the system, the space system including both satellite vehicles capable of broadcasting the L5 signal as well as the structure of the DNMS message embedded in the L5 signal, and the user segment in receipt of the DNMS messages. Each segment of DNMS will be discussed.

A. DNMS REQUIREMENTS

The summary of threshold and objective requirements of the DNMS are highlighted in Table 3; explanations of requirements follow. It is expected that - due to a significant period of time before a fully operationally capable constellation is in place - initial operations capable (IOC) requirements will be established for the system that are less stringent in execution than the final operations capable (FOC) requirements. While the FOC requirements represent significant capability, IOC requirements will likely consist of a control segment capable of transmitting a DNMS message and at least 1 satellite vehicle transmitting a DNMS message. Many requirements are designed around both the theorized system capacity discussed later, as well as disaster statistics.

FOC Requirements	Threshold Requirement	Objective Requirement
Trigger Criteria	200 killed - or - National disaster declaration	100 killed - or - National disaster declaration
Simultaneous support to events globally with 99.9% certainty	Up to 101 events	Up to 103 events
Simultaneous support to events globally with simultaneous DNMS messages and 99.9% certainty	Up to 126 messages	Up to 129 messages
Timeliness from notification of event start to broadcast on first supporting satellite over area	1 hr	25 min
Maximum event size	Global	Global
Minimum event size	50 km	10 km
Identify event location to within	16.66 km	3.33 km
Simultaneous satellite vehicles supporting a single event	1 satellite	3 satellites
Maximum message interval for single event support	1200 sec	600 sec

Table 3. DNMS Requirements

1. Trigger Criteria and Global Event Support

In order for an event to be considered sufficiently disastrous to be triggered and included within the DNMS, a minimum baseline of event requirements is established. The trigger criteria and thresholds of DNMS are different than the CRED disaster statistical analysis criteria. The trigger criteria has been approximately modified to match the potential bandwidth of the DNMS system. As new or additional bandwidth, signals or other technologies emerge, the trigger criteria can be modified to include more events and maintain 99.9% event and message coverage. Additionally, as higher fidelity statistics - including data on geographic size and distribution - are found, the trigger criteria again can be modified. Of note, DNMS is designed primarily around the predicted number of individuals to be killed, not affected by a disaster; in 2010, natural disasters killed approximately 450,000 individuals but affected approximately 200,000,000. Two assumptions are made regarding this design decision: other alert and warning systems are integrated with DNMS such that the vast majority of individuals affected are also notified through other means, and that based on more frequent triggers, the bandwidth of DNMS has insufficient capacity to report based on individuals affected.

In order for the DNMS to trigger, an event must be sufficiently severe that death is a probable outcome and be sufficiently significant that at least 100 individuals are predicted to be killed (vice 10 killed or 100 affected to be reportable in the CRED analysis). The objective requirement for simultaneous disaster events is matched to the adjusted expected number of total simultaneous events based on the predicted killed trigger threshold. Based on an average number killed for natural disasters of 349 individuals and a standard deviation of 7180, if a trigger event requires 100 individuals killed, 48.6% of events reported in CRED analysis exist below this threshold. This implies that of the 198.9 simultaneous events per day (0 to +3σ value), only 102 would be reportable. Using similar math for technological disasters with an average of 30.8 killed and a standard deviation of 53.1, a 100 individual trigger yields 90.4% below. This implies that of the 15.1 events (0 to +3σ value), only 1 would be reportable. Using 100 predicted deaths during an event as a DNMS event trigger yields 103 reportable worldwide daily separate disaster events. The numbers here assume normal Gaussian distribution which is untrue and requires further refinement, but can be used as a preliminary baseline approximation. The objective system trigger requirement is matched to this 99.9% accountable value of 103. The threshold objectives were calculated using similar analysis for 200 individuals killed as a system trigger, to ultimately yield 101 natural disaster and 0 technological disasters, or 101 total reportable daily separate disaster events worldwide accounting for 99.9% of events. Under the assumption that for many disaster events, it is possible to require multiple different DNMS messages be transmitted, this total reportable event number is multiplied by a 1.25 factor of safety to approximately ensure adequate bandwidth, raising the objective requirement daily total to 129 DNMS messages and threshold requirement to 126 DNMS messages.

2. Timeliness

The timeliness of the DNMS plays a significant role in establishing its overall effectiveness. Some disaster events, such as drought or hurricanes, can be forecast weeks in advance whereas other events, such as tsunamis, are much more limited; for instance, tsunamis can only be forecast after the mega-thrust earthquake has occurred but prior to waves reaching shore. Tsunamis represent one of the most impacting natural disaster events with one of the shortest forecast timelines, and will therefore be used to gauge timeliness requirements.

Along the seabed east of Japan, many seismometers are linked to transmitters on the ocean surface which automatically transmit potential tsunami events to satellites and downlink over the Japanese mainland. The process from detection to transmission to users can occur on the scale of seconds to minutes and is one of the timeliest in the world, but the system requires significant infrastructure and exists only in Japan. No global system - without similar local infrastructure - can match the speed of the Japanese system in reporting tsunamis when there may be only minutes from the occurrence of an event and the impact on individuals.

In December 2004 the longest recorded mega-thrust earthquake was observed off the coast of Sumatra, Indonesia creating a tsunami that killed over 230,000 individuals in 14 countries. The earthquake occurred at 00:58 UTC. By 01:23 UTC, the tsunami reached Sumatra and by 02:23, the tsunami reached Sri Lanka. The characteristics of tsunami waves change significantly from deep to shallow waters, and vary in speed from approximately 750 km/h to 20 km/h, respectively. South Africa experienced only 2 deaths from this tsunami, but at 8500 km from the epicenter, could have been affected as early as 11 hours after the earthquake. Generally, the range in time from earthquake to tsunami striking a coast is 25 minutes to 11 hours.

All communication links from detection, processing, intermediate transmissions and final transmission to users as well as adequate time for a user to act must be accomplished prior to 25 minutes elapsed in order to have a truly effective system. DNMS represents only one intermediate link and a final transmission path as components of a greater overarching warning system. The timeliness of DNMS is measured from the notification of a forecast or occurring event at the DNMS control segment to the transmission of a DNMS message in the space segment under the assumption that the detection, processing and transmission to the DNMS control segment is largely automated and nearly instantaneous. The timeliness objective requirement therefore is approximated at 25 minutes. The DNMS will rely on the GPS control segment, where a modernized satellite contact (without NDS operations) takes approximately 25 minutes. The control segment supports a substantial number of satellites through limited ground antennas. Resource conflicts occasionally occur, and it is possible - through routine maintenance, anomalies or other higher priority operations—that simultaneous DNMS message requirements must be broadcast to different satellites from the same ground antenna. In this case, one satellite support must be completed, resources shifted, and a second satellite contact performed. The threshold requirement therefore is 1 hour, under the assumption that completing a satellite contact, shifting resources and beginning a second contact will add approximately 10 minutes.

The DNMS is one component of an ideal warning system which can only ever be as responsive as the sum of its components. The DNMS offers many significant advantages through integration with other disaster notification systems, but the timelines or forecast required for some events such as earthquakes or tsunamis may be faster than DNMS can support. DNMS messages for related sub-disaster components of those events would be transmitted; for instance, forecast earthquake aftershocks or forecast sustained flooding following tsunamis.

3. Event Location and Size

Disaster events with the potential to kill vary significantly in size. Statistical information regarding size distribution is unavailable, therefore assumptions will be made. Tropical cyclones represent one of the geographically largest possible disaster events; typhoon tip in 1979 represents the largest tropical cyclone in recorded history with a diameter of 2,220 km. While this unique event could have covered half of the United States, it is possible other events such as drought or an epidemic outbreak could have global reaches. The maximum reportable event size threshold and objective requirements therefore are global. The geographically smallest possible disaster with 200 or more predicted deaths is likely a man-made event with significant potency. In such cases, it is hypothesized that reporting an event for a small town is realistically the smallest area requiring notification. The minimum event size objective requirement therefore represents a small town at 10 km; the minimum reportable event size threshold requirement represents a large town at 50 km.

Locating a disaster event of the minimum event size is dependent upon the resolution at which the system is able to identify the event center. It is assumed that the size of the reported event will be increased beyond the actual event in order to ensure the entire area is reported. With a resolution one third the size of the geographically smallest reportable event and a small increase in size, the majority of a reported event matches its actual event. The size resolution is therefore one third the minimum event size, or a resolution threshold requirement of 16.66 km, and objective requirement of 3.33 km.

4. Simultaneous Satellite Overlap

In order to ensure a receiver has the potential to receive a DNMS message, it must be within the footprint of a satellite broadcasting a DNMS message. Obscura or low elevation can prevent a handset from receiving and processing the signal, therefore, it will be assumed that satellites must be above 10 degrees elevation in order to be considered visible, even though many handsets can track satellites below this threshold if clear line of sight is available. If the space segment is transmitting a DNMS message to a user, the system is considered functional; therefore the threshold requirement is established such that at least 1 satellite in view is transmitting the DNMS message. The GPS is designed to minimize PDOP, therefore satellites have a high probability of being distributed throughout the sky, varying significantly in azimuth and elevation. In order to ensure message receipt in an environment with potential obscura such as buildings in an urban environment, the objective requirement is established such that at least 3 satellites in view are transmitting the DNMS message.

5. Message Reporting Interval

It is assumed that upon notification, the DNMS will react as quickly as is feasible to broadcast notification information over an event. Once the initial broadcast has occurred, the system duty cycle, or interval requirement, will determine the frequency at which the message is repeated. A high duty cycle will ensure that users receives the message as quickly as possible, but once the message is received, the additional transmissions of repeated messages are essentially wasted bandwidth that could have otherwise been used to transmit other DNMS messages. Under the assumption that the initial message and notification is transmitted as soon as feasible, a slower duty cycle can be chosen to balance bandwidth for longer disaster events. Six hundred second and 1200 second timing intervals were chosen for the objective and threshold requirements respectively; the system may transmit much more frequently than the 600 and 1200 second requirements based on available bandwidth and other simultaneously occurring events.

B. DNMS ASSUMPTIONS

Many specific details on the future operational implementation of the GPS L5 signal on block IIF, III and future GPS satellite vehicles are as of yet undecided. Details from operators and engineers at 2SOPS, mission planners at the Joint Space Operations Center (JSpOC), engineers and acquisition Officers at the Space and Missiles Center (SMC) GPS Wing have been aggregated throughout this document, but many assumptions must still be made on how DNMS messages would or could be handled, partly using message type 15 text messages as a corollary. In lieu of specific executable details, some realistic and extremely conservative assumptions about message capability, handling concept of operations, etc are made here and are assumed to be true throughout the remainder of this analysis.

Block IIF, III and future L5 capable satellite vehicles will, at a minimum:

- have adequate memory and buffer storage to hold and have access to broadcast a minimum of 32 L5 broadcast text or DNMS messages per navigation upload from the control segment.

- appropriately control the transmission timing of a text or DNMS messages in the L5 broadcast based upon compliance with other mandatory message timing requirements as defined in ICD-GPS-705C.
- have no restrictions on the frequency at which text or DNMS messages can transition between different messages, so long as the messages comply with the timing requirements as defined in ICD-GPS-705C in the L5 broadcast.
- have the ability to forecast the transmission windows for text or DNMS messages up to 1 week in the L5 broadcast based upon visibility forecasts.
- have adequate message slot availability to broadcast each text or DNMS message at least once in each 144 second super-frame period of time in the L5 broadcast.

Another significant assumption is that this system would potentially take years to reach FOC, and likely decades for a constellation of all L5 capable vehicles to be realized. The DNMS IOC would occur in the near term providing limited DNMS messaging capability with a small subset of healthy L5 capable GPS satellites.

The final and most significant assumption required for this system to be realized is that manufacturers will incorporate the processing of this additional data in their devices. Throughout the early 2000's, once manufacturers understood the advantages and potential profits from incorporating the GPS SPS C/A broadcast on the L1 frequency data stream into devices such as cell phones, GPS features were incorporated by default and have become ubiquitous. Similarly, by making this type of information available and known to consumers, manufacturers will be driven to incorporate into the operating systems of virtually all devices capable of receiving it. This demand can be described as a capitalistic imperative, as the required effort to utilize DNMS messages on a device already capable of receiving the L5 signal is largely insubstantial.

C. DNMS SPACE SEGMENT

1. L5 Bandwidth Analysis

Since the inception of GPS, the traditional legacy civil (C/A) SPS and encrypted military (P(Y)) PPS signals on the L1 and L2 frequencies have a fixed repeating 1500-bit frame, with 300-bit sub-frames, as currently defined in IS-GPS-200F. By defining each bit of the message, there is little flexibility in adding new data or changing data types that are broadcast for highly dynamic environments or changing system requirements without adversely impacting the space, control and user segment in catastrophic ways. There are several seemingly random unused bits reserved for future use, but they do not offer substantial flexibility or bandwidth that would be necessary to implement a disaster notification system. The GPS L5 SoL signal utilizes a modernized broadcast format in which various different 300-bit pre-defined message types are broadcast with specific timing interval requirements, as defined in IS-GPS-705C. Each message type being 300 bits long and transmitted at 50 bps means that each message type requires 6 seconds to fully transmit, to include message type identifier information, parity, error correction, etc. Table 4 adapted from IS-GPS-705C shows the required data and minimum interval requirements for the L5 signal messages, which is ultimately used to determine available bandwidth.

Message Data	**Message Type Number**	**Maximum Broadcast Interval****
Ephemeris	10 & 11	24 sec
Clock	Type 30 - 37	24 sec
ISC, IONO	30	144 sec
Reduced Almanac	31 or 12	10 min
Midi Almanac	37	60 min
EOP	32	15 min
UTC	33	144 sec
Diff Correction	34 or (13 & 14)	15 min*
GGTO	35	144 sec
Text	36 or 15	As needed
*When differential corrections are available. **Intervals specified are maximum; as such, the broadcast intervals may be shorter.		

Table 4. L5 Message Broadcast Intervals

Because the modernized L5 signal is not yet implemented, the concept of operations is not yet defined, and some vehicle capabilities not yet defined or constructed, there were several assumptions made in performing an analysis of available bandwidth; efforts have been made for assumptions to be conservative in terms of finding available bandwidth. Firstly, it was assumed that the 24 second interval requirement for message type 30–37 containing clock information will be met when any message of type

30 through 37 which contains clock information is broadcast, even if that broadcast meets a different timing requirement (i.e., Midi Almanac every 60 minutes). It was conservatively assumed that the reduced almanac data will be broadcast as message type 12, so as to not meet the clock information requirement. Also, the differential correction data is assumed to be available and will be broadcast as message types 13 and 14 instead of 34, again so as to not meet the clock information requirement. There were two types of analysis done: mathematical and simulation.

The mathematical analysis was performed by calculating the percentage of time that each message type requirement will be broadcast and subtracting those broadcast times to determine available time bandwidth time. Mathematically then, for required messages:

$$B = 1 - \sum_{1}^{m} \frac{MessageBro\ adcastTime}{MaximumInt\ erval}$$

The maximum interval for clock and reduced almanac was defined as choosing any element of the set of message types $\in \{30–37\}$ or $\in \{12,31\}$, respectively. The available bandwidth time as a percentage, B, is then:

$$B = 1 - \left(\frac{6}{M_{10}} + \frac{6}{M_{11}} + \frac{6}{M_{30}} + \frac{6}{M_{33}} + \frac{6}{M_{35}} + \frac{6}{M_{\in \{30\text{-}37\}}} + \frac{6}{M_{\in \{12,31\}}} + \frac{6}{M_{13}} + \frac{6}{M_{14}} + \frac{6}{M_{32}} + \frac{6}{M_{37}} \right)$$

$$B = 1 - \left(2 \cdot \frac{6}{24} + 3 \cdot \frac{6}{144} + \left[\frac{6}{24} - 3 \cdot \frac{6}{144} - \frac{6}{900} - \frac{6}{3600} \right] + \frac{6}{600} + 2 \cdot \frac{6}{900} + \frac{6}{900} + \frac{6}{3600} \right) = .22666$$

From an idealized mathematical analysis, 22.66 percent of the time, there is available bandwidth in the 50 bps stream of data for additional data types and information. In any given hour of 3600 seconds, broadcasting data at 50 bps, with each message lasting 300 bits, there are 600 messages transmitted. This means that, rounding conservatively, there are 135 available messages slots for text, DNMS or other messages. This mathematical analysis has an inherently flawed assumption in averaging for an indeterminate period of time that simultaneous message requirements will never occur to force earlier message transmission or arrivals. Because of this assumption, a more rigorous simulated analysis was performed.

The intent of the simulation was to determine a realistic and actionable method of maximum interval requirement implementation in order to find bandwidth availability. In this simulation, each 6 second block of time is referred to as a sub-frame, each 24 second block of time as a frame, and each 144 second block of time as a super-frame.

Figure 9 shows a graphical representation of message timing for the first 8 super-frames representing 1152 seconds of broadcast, though the analysis was performed for 3600 seconds to include at a minimum the longest time interval requirement of 60 minutes for message type 37 Midi Almanac.

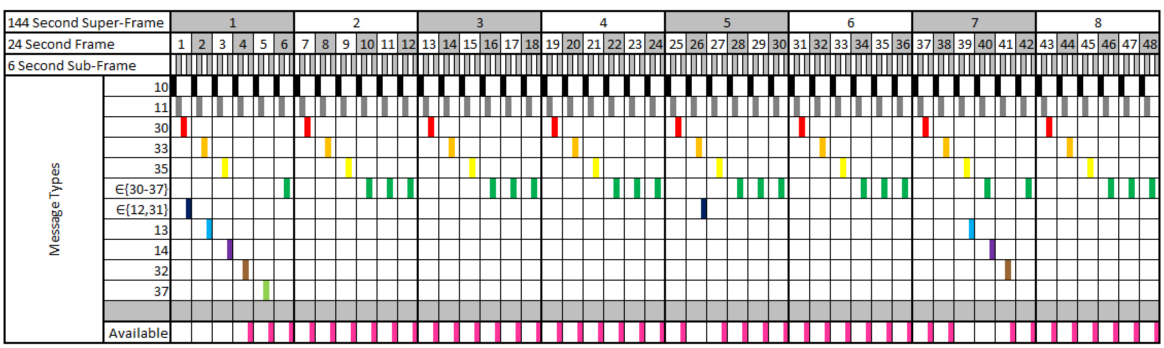

Figure 9. L5 Bandwidth Simulation

This analysis was performed by repeating message types 10 and 11 every frame in the first 2 sub-frame slots, as they represent the most constraining timing requirement. The 3rd sub-frame slot was used to meet the $\in\{30–37\}$ requirement, either through separate timing requirements or by selecting any generic element of the set. The 4th sub-frame slot was used for the remaining timing requirements. Several times in a one hour period, the requirements overlapped by sub-frame message slot and forced a message type to occur 1 frame earlier. This is a realistic occurrence that was not adequately captured using the mathematical percentage of time analysis. With these occasional overlaps, there were 133 of 600 total messages available for new data types. Extrapolated further beyond 3600 seconds, overlaps continue to occur, but do not drop hourly message averages to below 133. While mathematically there could be up to 22.66% of available bandwidth, a simple, realistic and implementable approach yields 22.17% of available bandwidth, which for the purposes of this analysis is sufficient.

A final assumption not yet mentioned is that no text messages of type 36 or 15, no new message type requirements, and no system or event driven message requirements were levied in addition to the interval requirements which would cause a message type to occur earlier than the maximum time interval. To compensate for these unknowns, it is assumed that an extremely conservative third of this available bandwidth could be otherwise occupied; therefore, a reasonable approximation and estimate is that 89 different DNMS messages per hour, per satellite vehicle are available to support disaster notification, while simultaneously not affecting the transmission of PNT GPS data.

2. Transmission Scheme

There are primarily two different transmission architectures to be considered in designing DNMS transmissions: rigid or dynamically allocated. This analysis assumes all block IIF and block III satellites are operational with FOC declaration and standard satellite vehicle attrition; therefore this analysis will assume 40 of the potential total 44 satellite vehicles are broadcasting healthy data.

A rigid system will use 'DNMS constellations'. A DNMS constellation is a relatively static and pre-defined subset of GPS vehicles required to transmit a DNMS message in order to ensure that a message is being transmitted to and received at a given disaster location for the entire duration of a disaster event. Individual satellite vehicles can exist within different DNMS constellations based on the configuration and transmitted data. Using rigid, fixed DNMS constellations, approximately 7 optimally chosen satellites vehicles are required in order to ensure worldwide coverage 99.99% of the time, with approximately 2–4 satellites in view of any location on earth at any given time. This assumes that all disaster events may be any size up to global with global DNMS transmission. In a healthy GPS constellation of 40 L5 capable vehicles, 5 unique DNMS constellations consisting of 7 vehicles each can be defined with 5 vehicles in reserve. Optimally choosing the 7 vehicles is a computationally difficult task. Using N choose R (nCr) combinatorial mathematics:

$$nCr = \frac{n!}{r!\,(n-r)!}$$

$$\frac{40!}{7!\,(40-7)!} * \frac{33!}{7!\,(33-7)!} * \frac{26!}{7!\,(26-7)!} * \frac{19!}{7!\,(19-7)!} * \frac{12!}{7!\,(12-7)!} = \frac{40!}{5 * 7! * 5!} = 2.70^{41}$$

There exist 2.7e41 possible vehicle combinations when choosing 5 structured 7 satellite vehicle DNMS constellations. Simplifying assumptions can be made in the control segment software that defines DNMS constellations such as ensuring no more than 3 vehicles from any given orbital plane are selected, ensuring that vehicles within an orbital plane are separated by more than 60 degrees true anomaly, etc. The modernized L5 signal is not limited to 32 PRNs in the way legacy signals are, so the number of possible combinations to be optimized will increase exponentially as healthy L5 capable vehicles increase beyond 40, though a number of additional simplifying assumptions to computational complexities can be added. It is assumed that the control segment will have sufficient computational capacity and simplifying assumptions to forecast and select satellites for each of the 5 DNMS constellations. Once defined, the constellations need not change unless a new satellite launches, a vehicle health changes, significant phasing maneuvers or station-keeping maneuvers are performed, etc.

Based on an objective requirement for retransmission time of 600 seconds, each message must be transmitted once every 10 minutes, or each message must be transmitted 6 times in each hour. In that same time period, each vehicle, and therefore, each DNMS constellation is capable of transmitting 89 unique L5 messages. Based on the ability to insert 2 separate DNMS messages in each L5 message, each vehicle is capable of supporting disaster events with 30 separate and unique disaster messages within the DNMS stream. Using this rigid broadcast scheme of 5 defined 7 satellite vehicle DNMS constellations with 5 additional vehicles available as a reserve for additional tasking ultimately yields 150 simultaneous disaster messages, meeting the objective requirement of 103 simultaneous events and 129 simultaneous DNMS messages. With this scheme, there is potential bandwidth not utilized based upon satellite footprint overlap, but otherwise is an efficient system.

The second option is to use a dynamically allocated transmission scheme instead of rigid and fixed DNMS constellations. In this scheme, as an event is reported to the control segment for inclusion as a disaster event, satellite vehicles are automatically selected from the available pool of vehicles such that visibility to the geographic region is tailored and specific. During visibility to the disaster event each orbital pass, the message is re-inserted into the data transmission, and upon leaving visibility that bandwidth is freed. Instead of all DNMS constellation vehicles transmitting the message continuously worldwide as is true in the rigid scheme, sets of vehicles and times for vehicles are chosen for each event, significantly increasing the available bandwidth of the system. This system reduces the initial computational complexity of defining mission constellations as well, but performing a bandwidth throughput analysis is difficult without higher fidelity statistics on disaster event size and distribution.

The fixed DNMS constellation option is chosen based on its predictability and sustained global coverage within DNMS constellations. In either scheme, a forecast message will not be incorporated into a DNMS message until the message event start time (i.e., message start time, not actual event time) is less than 1 week in advance. This ensures that only current and valid data is broadcast, reduces the effects of data aging prior to broadcast, and reduces the possibility of annual ambiguities in date systems. Additionally, in either transmission scheme an identical message will occasionally be broadcast over a specific area from multiple satellites in view; because the messages are identical in content and neither message has higher or differing precedence, no conflict exists in the handset software in characterizing the disaster event. In cases where messages differ, a precedence scheme will be developed to allow receivers the ability to interpret differences in message content.

3. DNMS Message Data Structure

ICD-GPS-705C defines the text message type 15 data structure as shown in Figure 10. A standard text message has 232 information bits available for text, after 68 bits are utilized in defining message type, PRN, CRC, etc. Of note is that 4 bits are specific to a message page number in the case where a single text message string spans multiple broadcast messages.

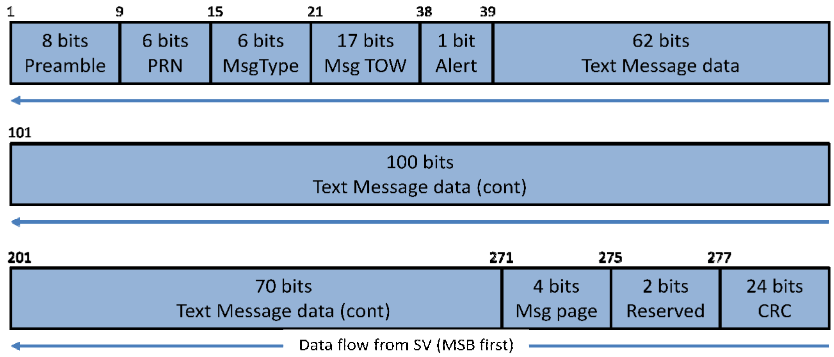

Figure 10. L5 Message Type 15 - Text Message (From ICD-GPS-705C)

For DNMS to broadcast disaster specific information within L5 data, there are two possible methods. The first option is to use a pre-defined type 15 text message and add an overhead to the 232 data bits to allow receivers to interpret the text message as a DNMS message. The second and preferred option is to create a DNMS message type in the ICD-GPS-705C. The latter option would need to be incorporated into the control, space and user segments in order to ensure proper generation and receipt of a new message type. In the current revision of ICD-GPS-705C, 6 bits are used to identify the message type number, allowing 64 unique messages. Currently only 14 of the 64 message types are defined, so that there is adequate availability in the existing message structure for a new message type. A hypothesized message type 44, DNMS Message, is shown in Figure 11.

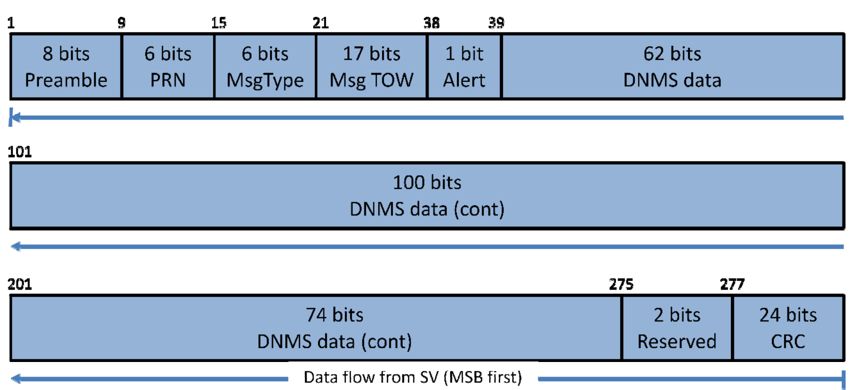

Figure 11. Proposed L5 Message Type 44 - DNMS Message

The DNMS message structure does not require uniquely identified pages, which adds 4 data bits from a text message. In total, a DNMS message may utilize 236 bits, and will add the following data fields within the DNMS data:

MSGID: The DNMS message identification is a code unique to an individual broadcast event. This code increments by 1 for each unique event that is programmed into the control segment chronologically, up to a maximum of 256 events, at which time the counter resets to 0 and begins counting again. This scheme minimizes the likelihood that two MSGID values overlap, under the assumption that in a 128 hour period (see DUR field), there will be fewer than 256 different events. The MSGID field serves one primary purpose: to uniquely identify an event and determine when an event's information is updated and rebroadcast in order to associate multiple messages together. Of note, multiple messages with differing or like MSGIDs can be transmitted, ultimately supporting and providing information to the overarching disaster event. The MSG ID field uses 8 bits of the DNMS data stream to define the 256 event possibilities.

ETYPE: The event type field in the DNMS message describes the category of disaster event, ultimately derived from the most common and impacting disaster events to since 1900 as shown in the CRED epidemiology report. This field has 16 possible states, utilizing 4 bits of the data stream. Fifteen unique event types are defined in Table 5. One additional data bit is available to be defined in future versions of ICD-GPS-705. In cases where multiple event types occur simultaneously, separate DNMS messages would be broadcast to allow flexibility and differentiation in event locations, areas and times, either through different or like MSGID fields. Optionally, in future versions of this type 44 L5 message, the 4 ETYPE bits can be expanded to 16 using additional available bits such that each event utilizes a separate bit. This allows multiple simultaneous event types for the same overarching disaster, assuming all other message parameters are identical. For instance, if heat, drought and fire all occur at the same time, duration, location, etc, a single message could then be used instead of 3 separate messages. If however, the time, durations, locations or other fields vary, which is more often the case, the current ETYPE implementation scheme is more applicable.

Event Type	Data Bits (4)
Extreme Heat	0000
Extreme Cold	0001
Blizzard	0010
Hurricane or Storm	0011
Tsunami	0100
Fire	0101
Radiation	0110
Earthquake	0111
Volcanic Eruption	1000
Flooding / Storm Surge	1001
Epidemic / Outbreak	1010
Insect Infestation	1011
Mass Earth Movement	1100
Drought	1101
Armed Conflict	1110

Table 5. ETYPE - DNMS Message Event Type

PREC: The message precedence field is intended to allow multiple messages with the same MSGID number to be appropriately processed and interpreted by a receiver. Four different precedence levels are defined, as follows: 1) Original unmodified message broadcast, 2) All information fields are replaced with new message information for existing MS ID, 3) Information is added in aggregate to existing MSGID, 4) Disregard or cancel event MSGID prematurely. In cases where multiple differing messages are received (i.e., no original message but a field replacement message from one satellite and a field aggregation from another), the combination of event start and MSGID would be used to interpret the applicable data. Eventually with MSGID rollover it would be possible for ambiguities to exist, in which case the control system software would cancel the existing message and create a new original MSGID. The control segment must be programmed in a way so as to not allow transmission of two messages with like MSGID fields, differing disaster details and inappropriate PREC field (i.e., Original Message).

Event Precedence	Data Bits (2)
Original Message	00
Field Replacement	01
Field Aggregation	10
Premature Cancellation	11

Table 6. PREC–DNMS Message Event Precedence

LOC: The LOC field is used in combination with the size, shape, ratio and direction fields to allow great flexibility and precision for a receiver to determine if the current PNT calculated position is within the geometric proximity of a disaster event. The location field translates to a World Geodetic System 1984 (WGS84) latitude and longitude and assumes that disaster events occur on the surface of the earth, or apply to all elevations at that latitude and longitude. The resolution of the location field is intended to be sub-10km. In defining the longitude value, based on the WGS84 defined earth radius at the equator of 6,378,137 m, using 1 bit to define west or east of the Greenwich meridian and 11 bits to define 2048 unique values counted to the west or east, the system resolution is 9.78 km. In defining the latitude, 1 bit is used to define north/south of the equator and 10 bits to define 1024 unique values counted to the north or south. In total, the LOC field utilizes 23 bits of the DNMS data message to arrive at any location on earth no more than approximately 3.13 km away (for worst case at equator). Note that due to the oblateness of Earth, the resolution is slightly higher fidelity at the polar north and south; latitude and longitude values at the pole will be no more than approximately 3.01 km away.

SIZ: The size field is defined as the radius of the event from the center location defined by LOC in units of LOC resolution increments, as defined in Table 7. In cases where the SHP and RAT fields define different shapes than circles, the SIZ field denotes the radius equivalent from shape center to long axis shown in Figure 12. The SIZ field accommodates event sizes up to global, differentiating between 1024 LOC radius resolution value increments (~10,015 km) from center LOC as hemispherical and one additional bit state to represent a single global event. In an effort to minimize data bits used, a pseudo-logarithmic scale is implemented. With 16 unique values to define the event size, 4 bits of the DNMS message are used.

Radius Increments	Data Bits (4)
1	0000
2	0001
4	0010
6	0011
8	0100
10	0101
20	0110
40	0111
60	1000
80	1001
100	1010
200	1011
400	1100
600	1101
1024	1110
Global	1111

Table 7. SIZE - DNMS Message Event Size

SHP: The shape field of the DNMS message type specifies a circular or rectilinear base shape, utilizing a single bit of data.

Event Shape	Data Bit (1)
Circular	0
Rectilinear	1

Table 8. SHP–DNMS Message Event Shape

RAT: The ratio field specifies the ratio of major and minor lengths of the shape defined by the SHP field. The ratio can be 1:1, 3:2, 5:2 or 5:1 utilizing 2 data bits. Figure 12 shows the usable shape and ratio combinations, as well as size.

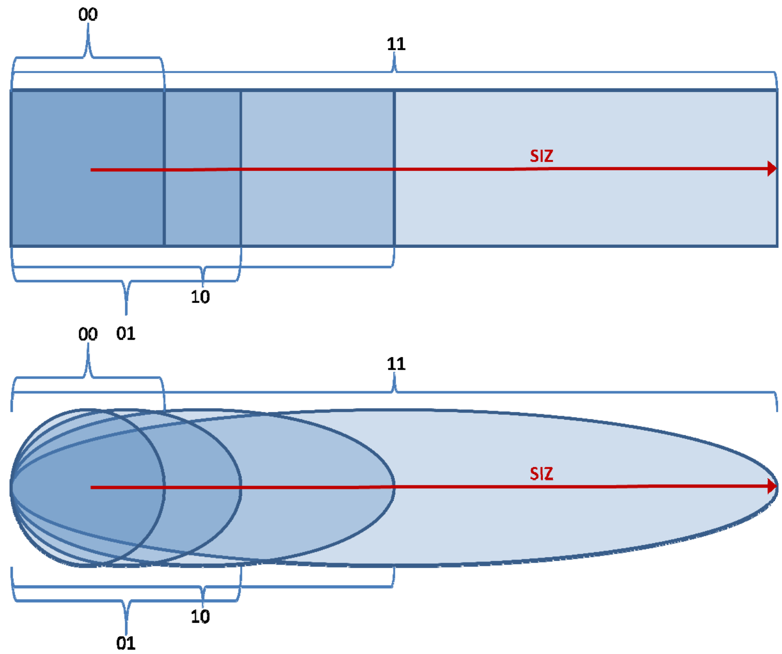

Figure 12. DNMS Shape Ratio Examples

Shape Ratio	Data Bits (2)
1:1	00
3:2	01
5:2	10
5:1	11

Table 9. RAT–DNMS Message Event Shape Ratio

DIR: The direction field allows rotation of the shape in order to tailor to geographic region. Rotation is allowed through 8 states of 22.5 degree increments, utilizing 3 data bits as defined in Table 10. Due to shape symmetry, 1 data bit is saved in that 16 directional states need not be defined. In cases where SHP field denotes circle and RAT denotes a 1:1 axis ratio, the DIR field is defaulted to 0 degrees rotation and ignored by receivers.

Shape Direction	Rotation	Data Bits (3)
N	0 degrees	000
NNE	22.5 degrees	001
NE	45 degrees	010
ENE	67.5 degrees	011
E	90 degrees	100
ESE	112.5 degrees	101
SE	135 degrees	110
SSE	157.5 degrees	111

Table 10. DIR - DNMS Message Event Shape Direction

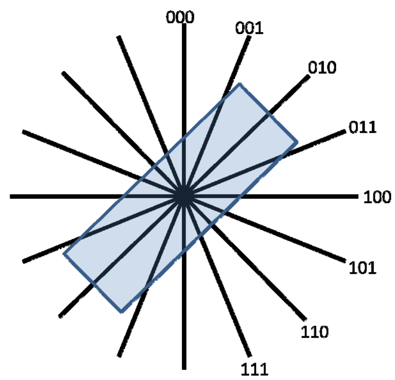

Figure 13. DNMS Shape Direction Example

TIM: The time field defines the beginning time of the disaster event. Two pieces of information are used: the day of year in which the event starts being defined using GPS time as already calculated using other clock and ephemeris messages of the L5 signal combined with the local receiver processing, and the number of 1 hour increments since the beginning of that Julian day. Note that because the maximum event duration (before rebroadcast) is one year as noted under DUR and constraints are placed on how far in advance messages can be transmitted, yearly ambiguities will not occur. Ambiguities can additionally be avoided by control segment constraints in defining new MSGIDs. Note also that the number of bits required to define a week number (6 bits) and hours into the week (8 bits), vice a day of year number (9 bits) and hours into the day (5 bits) are identical at 14 bits. This scheme yields a time resolution of 1 hour.

DUR: The event duration is defined as the time from the start of the disaster event until the forecast or predicted end. Disaster events can range in scale from minutes to months or years; therefore the DUR field uses a pseudo-logarithmic scale as shown in Table 11. This scheme assumes a minimum duration of 1 hour, a maximum event duration of 1 year or 8760 hours, and a maximum time resolution of 1 hour. If an event spans beyond 1 year, a new DNMS message will be created and transmitted with identical DNMS MSGID, with new updated TIM and DUR, utilizing the precedence field, or re-creating the message itself as necessary. Five data bits are utilized in defining duration states.

Duration	**Duration**	**Data Bits (5)**		**Duration**	**Duration**	**Data Bits (5)**
1 hr	1 hr	00000		96 hr	4 days	10000
2	2 hrs	00001		120	5 days	10001
3	3 hrs	00010		144	6 days	10010
4	4 hrs	00011		192	8 days	10011
5	5 hrs	00100		240	10 days	10100
6	6 hrs	00101		480	20 days	10101
7	7 hrs	00110		720	1 month	10110
8	8 hrs	00111		1440	2 months	10111
9	9 hrs	01000		2160	3 months	11000
10	10 hrs	01001		2880	4 months	11001
12	12 hrs	01010		3600	5 months	11010
18	18 hrs	01011		4320	6 months	11011
24	1 day	01100		5040	7 months	11100
36	1.5 days	01101		5760	8 months	11101
48	2 days	01110		6480	9 months	11110
72	3 days	01111		8760	1 year	11111

Table 11. DUR–DNMS Message Event Duration

LKL: The event likelihood field has 2 possible values of watch and warning, utilizing 1 bit of the data message. Broadcasted forecast events can be updated with like MSGID and appropriate PREC value to articulate the transition to an actual event occurring, from watch to warning.

Event Likelihood	**Data Bits (2)**
Watch: Event is probable but not yet observed	0
Warning: Event is occurring	1

Table 12. LKL–DNMS Message Event Likelihood

TXT: The text code field allows a significant number of pre-defined messages to be programmed into handsets, with localization provided in software through manufacturers for different languages and cultures, with the message intent defined in ICD-GPS-705. Only 21 individual messages are defined in Table 13, but 32 total bits are allocated for this function to allow additional text messages to be defined in the future. Bit 2 toggles on or off bits 3–5 of the 32 bits, which are coded for directional evacuations, whereas every other bit can be toggled in conjunction with other bits to allow for simultaneous messages within a single DNMS message. For instance, by combining bits 2, 4 and 11–13, a message could be sent directing to evacuate to the East while seeking higher elevations and rationing food and water; or by combining bits 8–12 and 15, a message could be sent to immediately seek and reinforce shelter, avoid outdoor movement, to ration food and water and expect power outages. In the case of 'outward' evacuation, the handset has received the event center location and has calculated the current location through other messages and PNT data, and is able to calculate which direction is locally deemed 'outward'. The text message is intended to be flexible to allow direction be provided in a wide range of scenarios.

Text Message	Data Bits (32)
Check Local Emergency Alerts	1-------------------------------
Evacuate (Directional)	-1------------------------------
Evacuate to the North	--000---------------------------
Evacuate to the North-East	--001---------------------------
Evacuate to the East	--010---------------------------
Evacuate to the South-East	--011---------------------------
Evacuate to the South	--100---------------------------
Evacuate to the South-West	--101---------------------------
Evacuate to the West	--110---------------------------
Evacuate to the North-West	--111---------------------------
Evacuate Outward from Center	-----1--------------------------
Evacuate (General)	------1-------------------------
Take Shelter Immediately	-------1------------------------
Reinforce Shelter	--------1-----------------------
Avoid Outdoor Movement	---------1----------------------
Ration Food	----------1---------------------
Ration Water	-----------1--------------------
Seek Higher Elevations	------------1-------------------
Seek Lower Elevations	-------------1------------------
Predicted Power Outages	--------------1-----------------
Predicted Communication Outages	---------------1----------------

Table 13. TXTCODE–DNMS Message Event Text Message Codes

A single DNMS message, in total occupies 99 of the total 300 data bits. Subtracting overhead fields such as PRN or CRC, 137 bits remain unused. Two complete DNMS messages can occupy the same L5 message, so long as a single TRG trigger bit flags the second half of the message to be valid and processed by a receiver. Thirty seven bits remain unused and available for future allocation or modification of the type 44 DNMS message structure. Figure 14 shows the L5 type 44 message structure in total, containing two separate DNMS messages.

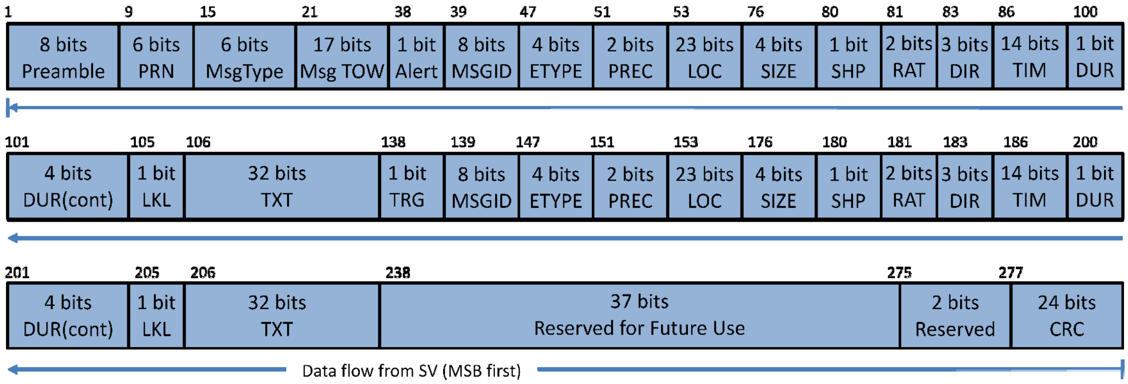

Figure 14. Refined L5 Message Type 44–DNMS Message

Hurricane Sandy of October 2012 can be used as a case study of how multiple DNMS messages can be broadcast to satisfy requirements for a single natural disaster event. Hurricane Sandy broke land in the later stages of the storm system over Brigatine, NJ. While the effects of the hurricane were felt across approximately 24 states, it was considered most significant with severe damage and deaths in New Jersey and New York. In New York in particular, a storm surge was experienced that flooded streets, tunnels and subways. Substantial damage was incurred along the Atlantic coasts of both states with sustained power outages. As the storm's predicted path approached the U.S. east coast, an initial DNMS message would have been broadcast with several days' warning, as shown in the Figure 15 example. The initial message would have held enough information to alert that an incoming hurricane with deadly force was forecast to strike, and to direct individuals to take and reinforce shelter while avoiding outside movement, while expecting power outages and flooding. As the storm struck New Jersey and the storm surge began flooding New York, the original message could have been updated via precedence or a separate message transmitted warning of an actual hurricane, flooding and power outages also shown in the Figure 15 example. All messages are tailored geographically and temporally.

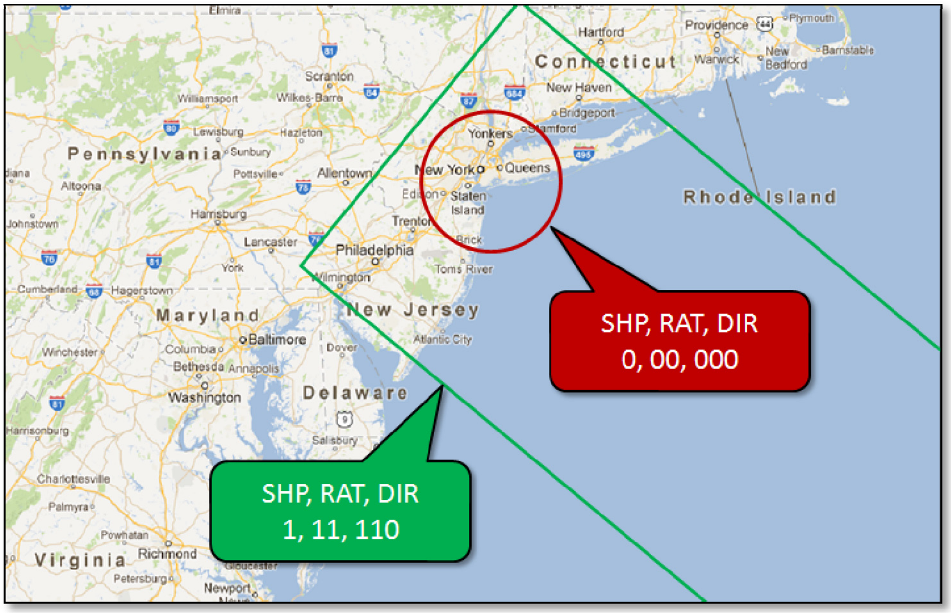

Figure 15. Overlapping Event Example (Shape, Ratio, Direction)

It should be noted that while this case study only specifically addresses the impact of Hurricane Sandy on the United States, were this a real DNMS event, the hurricane's progress and impact through the Caribbean would have been broadcast as well to report on a worldwide scale.

D. DNMS CONTROL SEGMENT

Similar to the GPS control segment, the DNMS control segment is responsible for the command and control of DNMS data, to include transmission to GPS satellites from worldwide ground antennas, receipt and functional verification of DNMS messages within the GPS signal from worldwide monitor stations, both through the GPS MCS, as well as communications with other disaster organizations.

The Air Force Weather Agency (AFWA) headquartered in Offutt Air Force Base, Nebraska would adopt the lead DNMS command and control role as a military organization to interface with the GPS control segment, as well as to interface with a variety of international organizations responsible for aggregating and transmitting disaster notification information. The AFWA may or may not adopt the role of international command and control for disaster notification as depicted in Figure 6; as such, the UN GDACS may optionally adopt the international command and control role and relay information to AFWA for transmission. Figure 16 shows the information process flow from a variety of organizations to GPS users.

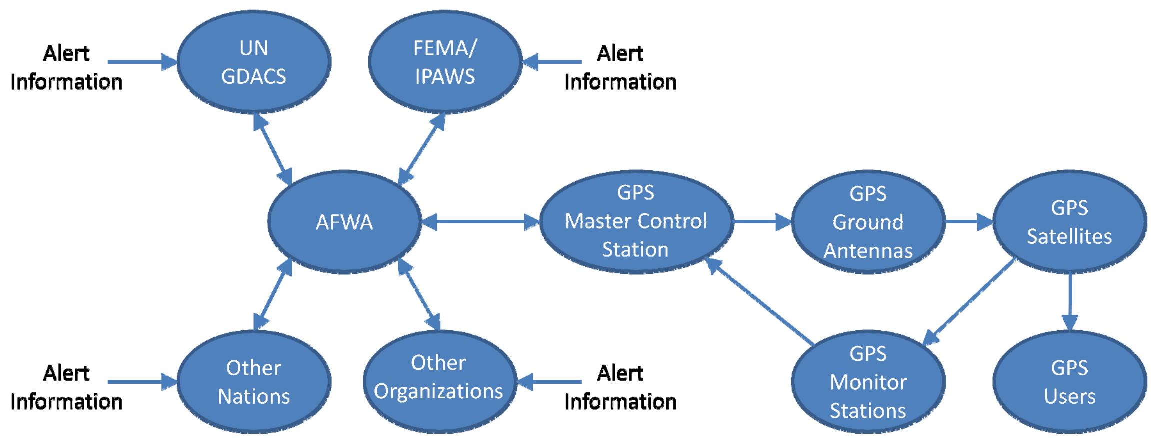

Figure 16. DNMS Control Segment Information Flow

The primary communications protocol used in transporting disaster notification information to and through the DNMS control segment would be based on the CAP standard, through secured communication transmission lines. The AFWA would be responsible for receiving all alert information, filtering duplicate events from different organizations (i.e., UN and FEMA simultaneously report for the same event with minor variations in parameters should yield a single DNMS event), adding DNMS specific event fields and information in the XML format as a modified CAP standard, and relaying the success of event notification to source organizations as reported from the GPS MCS. Event information reported from AFWA to the GPS MCS must contain all required data to be transmitted as an L5 message type 44 - DNMS Message. Software at the GPS MCS will be largely automated and schedule satellite support contacts based upon priorities from AFWA. The GPS MCS will also have previously defined the required DNMS constellations to simplify the transmission process. The GPS MCS, dedicated ground antennas and AFSCN ground antennas are assumed to have adequate capacity of satellite contacts to support DNMS with necessary data uploads, as DNMS and PNT information can be uploaded in the same data sets.

E. DNMS USER SEGMENT

The DNMS user segment consists of any device or user in receipt of a DNMS message through the L5 GPS signal. There is no specific design specification or implementation intended, rather the commercial industry is expected to integrate DNMS processing into devices. If necessary, local governments can mandate that GPS-enabled devices sold are able to process DNMS data, similar to U.S. mandates for mobile phones being IPAWS CMAS compliant.

The most basic functionality of a DNMS receiver would be to report DNMS event information for an event in which the receiver is located. Advanced capabilities could include reporting disaster event information for other on-going events or past detected events, displaying disaster regions or evacuation routes on a map, displaying evacuation directions and alert information as an overlay to other device information and many, many more. The original design of GPS receivers simply calculated [primarily] latitude, longitude and elevation, but modern receivers display current locations on satellite imagery with real-time traffic overlays and turn-by-turn directions to destinations, etc; it is anticipated that similar commercialization and design innovation will inspire new ways to process and integrate DNMS data, so long as all receivers maintain basic functionality. One handset may simply process location and display alert information such as "Flooding in progress for your area, evacuate to the North-East," etc, while another may display satellite imagery based map with evacuation route and traffic overlays. In either case however, the receiver is able to continually determine and re-determine if DNMS messages are applicable based upon the currently calculated GPS position. Utilizing the DNMS MSGID and PREC scheme, handsets are able to determine how to appropriately handle multiple messages or duplicate messages from the same or differing satellites.

F. ADDITIONAL DESIGN CONSIDERATIONS

1. Interference

The suite of GPS signals is inherently susceptible to interference. Power levels for received signals at ground user equipment are generally lower than the background radio frequency noise; it is only due to correlation of DSSS that the signal itself can be recovered and its data processed. Reports of interference for both civilian and military signals occur frequently, within the United States as well as abroad; most often this interference is inadvertent as uncorrelated noise bleeding into the GPS spectrum, but the sophistication of electronic warfare has increased in recent years such that adversaries are capable of more technically advanced attacks on GPS. Just as the miniaturization and proliferation of electronics brings GPS capabilities to individuals around the world, they also bring those same capabilities to adversaries. As an electronic warfare axiom goes, "The day the first transmitter was invented, so too was the first jammer."

In early 2013, a team from MIT with the cooperation of a witting yacht crew performed a proof of concept navigation attack as if a malicious attacker were spoofing GPS. GPS signals were slowly overpowered with a compilation of artificial signals which successfully steered the yacht 100 miles off course, and then followed a parallel track to the original course, all while the on-board navigation systems and other systems dependent upon GPS reported the location on the original track (Saarinen, 2013). The sophistication of attacks on GPS has increased exponentially in recent years, and DNMS data inserted into the GPS signals is also inherently susceptible. Also occurring in early 2013, computer hackers interfered with a television based emergency broadcast system in northern Michigan by reporting to and alerting the public that a zombie apocalypse was underway (Huffington Post, 2013). This highlights the susceptibility of emergency broadcast systems. Had the attackers intended malicious or nefarious effects, they could have synchronized attacks with other emergency broadcast systems and used more subtle and realistic alerts to cause mayhem. Emergency broadcast systems and GPS based electronic systems are constantly tested for vulnerabilities and exploited when available. If DNMS data is broadcast, it is extremely probable that it will not take long before spoofed disaster notification broadcasts are received by users.

It is likely that precluding such attacks on DNMS is impossible, but there are steps that could be taken either technologically, procedurally or according to policy in order to make them less likely; unfortunately, each step has significant effects on the design and operation of the system as a whole. The L5 SoL signal already exists in a more protected portion of the EM spectrum than other GPS signals, but it is still susceptible to interference.

One option to prevent malicious spoofing is to utilize encryption or a type of coded or authenticated rule-sets similar to parity. In order for encryption to work however, keys must be distributed to users via some data transfer mechanism wherein keys would not be available to an adversary of this system. Key distribution on this scale is unlikely. Message authentication via rule-sets or checksum is possible, similar to the way parity or checksums in credit card or IMEI numbers operate, such as Luhn, Verhoeff or Damm algorithms. For instance in the case of credit cards, it is statistically improbable that randomly choosing 16 base 10 numbers will yield a potentially operational credit card number; there are certain rules in place to ensure every number is provided by a card distributor error free. For this scheme of authentication to work however, those rules must be safeguarded as if they were an encryption key, otherwise an adversary may create numbers which abide by those rules and spoof a legitimate signal. In this scheme, receivers would require the rules be coded and stored locally in order to detect authenticated signals; were the rules to remain concealed, it is still possible to use a compromised receiver to brute force and discover authenticated codes for exploitation. In both cases, additional bandwidth for the encryption key or authentication key is required which reduces the overall bandwidth of the DNMS system. The more complicated the key or rule-sets, the fewer DNMS messages can be transmitted. Ultimately, no technological system can be created that is impervious to reverse engineering or attack.

Another option is to utilize international policy and law in order to deter such attacks on DNMS. Attacks on GPS signals most commonly occur from terrestrial based transmitters (vice airborne or spaceborne) where approximate geo-location is possible. By using international policy in cooperation with local and cooperating law enforcement in the countries affected by said interference, perpetrators can be searched for, potentially arrested and tried in a court of law. The United Nations may provide a framework for such international policy. Numerous articles of the Universal Declaration of Human Rights would be violated by such an attack, depending upon the attack's severity and intention. Not all countries, including the United States, have signed many United

Nations policies or protocols, so finding a standard baseline of policy would be difficult. Another option in international policy is to use relationships the United States shares with other nation states directly. DNMS is provided by the United States with the cooperation of local, regional or national reporting nodes. Agreements would need to be in place between the United States and other nation states that persons or organizations intentionally interfering with DNMS be prosecuted under the full extent of local and international law, in order for the DNMS service to be provided and for events within those national boundaries to be reported. Unlike PNT data transmitted through GPS signals, DNMS data could be manipulated by the United States in a way so as to not report events that occur within certain geographic boundaries. These actions would likely deter most, but ultimately not prevent some, attacks.

2. Additional Modernized GPS Signals

Other modernized GPS signals, such as the L1C, L2C or military only M-code have the same potential for underutilized bandwidth and the same the same message based construct that the L5 signal has. Modifying the GPS ICDs, control segment and space segment to accommodate DNMS on the L5 signal, and making the requisite policy changes to institute a disaster notification system over GPS represent the majority of obstacles and required changes in order to support other modernized signals. The relationship of data flow between signals is the major design decision that would need to be addressed. The data can either be replicated and broadcast across all DNMS capable signals to ensure receipt, in which case no additional bandwidth is available from the additional signals but would reach a receiver regardless of which modernized signal is utilized, or different messages can be broadcast on different signals, which would force receivers to track and process data for all modernized signals in order to ensure receipt of a message and utilize a more significant portion of the total available bandwidth. The question ultimately depends upon how adequately the L5 only DNMS bandwidth is able to account for disaster messages, and how receiver manufacturers design receivers.

By simultaneously transmitting data on all 3 modernized civilian signals as parallel transmission on different channels, the data can effectively be multiplexed to allow 4 times, the bandwidth so long as users receive all channels. With one additional channel, the bandwidth could be increased to 8 times, etc, however in this scheme, if a single channel is not tracked, no data is able to be processed.

When considering the military M-code as an additional modernized signal to include DNMS data upon, it is important to also consider what differences in data would be present between the civilian and military signals. Similar to the potential difference of civilian C/A and military P(Y) PNT data on legacy signals, a potential exists to tailor DNMS data for military forces, while still providing baseline support for worldwide use. This option would utilize more of the overall available bandwidth, and could provide higher fidelity tailored messaging for areas of military operations.

3. Commercialization of DNMS Data

Using different signals, encryption, authentication schemes or controlling geographic boundaries can allow the control segment to control DNMS message receipt to different user groups. The United States and the Russian Federation both utilize encryption to control data flow between civilian and military user groups for GPS and GLONASS GNSS respectively. The Galileo GNSS is an example of a system where, by controlling information flow, the civilian PNT data is commercialized wherein differing levels of service yield differing performance levels. The GPS DNMS could be commercialized at two different and mutually exclusive levels: national or individual service. Either method to commercialize would have significant implications on the design of GPS DNMS, and the level of international support the system would receive.

Similar to using international law and policy combined with the threat of discontinued service to garner nation state support, the service itself could be controlled to only report events within a country that provides to the United States government an annual minimal service fee. While unlikely, the cost of modifying the GPS and the sustained costs of operations would be balanced evenly in a sustainable way. One option of balancing costs is to prorate based on a nation's GDP in order to allow access for poor or rich nations. It is vital that the DNMS service scheme utilized not be priced in a way to as to be cost prohibitive to any nation.

The second option is to use encryption to allow DNMS messages be received only by paying customers, or to split between a baseline free level of service and an increased level of service which the United States government would be contractually obligated to provide. The cost of modifying the GPS and the sustained costs of operating would be balanced evenly in a sustainable way. The negative consequences of bandwidth occupation and cryptographic key distribution processes apply. Also as noted in the national level scheme, it is vital that the DNMS service not be priced in a way so as to be cost prohibitive to any individual.

4. WAAS

GPS satellites are not the only satellites which transmit GPS data. GPS Wide Area Augmentation Service (WAAS) satellites operated by the Federal Aviation Administration (FAA) act as a satellite based augmentation system (SBAS) to transmit real-time clock, ephemeris and ionospheric corrections to GPS PNT data over north America, intending to provide accuracy equivalent to Category 1 ILS primarily for aviation use (FAA, 2013). The data is transmitted in 5-second increments on GPS PRNs other than those defined in the operational GPS ICDs, and commercial equipment manufacturers have designed high performance handsets and receivers to utilize the additional correction information in order to provide significantly improved performance. Similarly, on an international scale, the European Space Agency has implemented the European Geostationary Navigation Overlay Service (EGNOS) which provides real-time corrections to the GPS, GLONASS and Galileo GNSSs primarily for aviation use over the European Union and Africa. Many other SBASs exist.

Combining WAAS, EGNOS or other SBASs with DNMS data may provide an effective augmentation or link replacement to DNMS. SBASs to include WAAS and EGNOS are generally broadcast from geostationary satellites, which has several benefits for broadcast signals. Based on the geostationary orbit, only ~3–4 satellites total are required for continuous near worldwide coverage (limited coverage at polar north and south without additional satellites). Additionally, because the relative satellite position remains comparatively static in the sky, updated data can be transmitted and received continuously in near real-time without changes in visibility.

One major advantage to utilizing SBASs is that DNMS data can be inserted on one or many PRNs newly created and dedicated to the DNMS mission. These PRNs would be broadcast at the same GPS SPS frequency (legacy signal) and received by WAAS capable receivers. New dedicated PRNs continuously broadcasting DNMS data would dramatically increase the bandwidth of the overall system. Additionally, using WAAS or other SBASs as the primary DNMS data link would greatly simplify the operational communication schemes and timelines.

Another option to further simplify the DNMS design is to create one or many PRNs and transmit DNMS data through commercially leased transponder space. This scheme would require a central command and control location, 3–4 ground transmission sites, and leased transponder space on 3–4 geosynchronous satellites. The FAA has previously tested and provided WAAS correction data on commercially leased transponder space on INMARSAT-4 F3 (FAA, 2013). These newly created PRNs would also be broadcast at the same GPS frequency. Under this scheme, the existing GPS control and space segments do not require modification and ultimately the overall cost of implementing the DNMS system is significantly reduced. Response timeliness also has the potential to increase using SBAs, wherein a continuous data link is established. Under the current GPS control segment paradigm, a connection must be established in real-time, occupying precious minutes that otherwise could have been used to alert individuals. Also worth considering is that because the WAAS corrections exist on GPS frequencies, it is not in the protected spectrum space of L5 and is potentially more prone to inadvertent interference. Leasing commercial transponder space for a PRN based GPS SBAS ultimately has significant potential for DNMS, with many benefits.

5. GPS Emergency Messaging System Patents

In January of 2010, U.S. patent number US7650136 B2 was published as a continuation to U.S. patent application Ser. No. 10/268,096 filed in October of 2002, wherein emergency messaging data is superimposed onto GPS signals. The patent includes information on the modification of the GPS segments in order to "…enable distribution of emergency messages nationally and globally while minimizing investment in new infrastructure … tailored to geographic region …" (Schnabel, 2010). While this patent differs in many implementation details and has different areas emphasized in specificity, the core functionality is essentially the same: each has response centers or aggregating nodes at various levels, a GPS control segment responsible for transmission to satellites, GPS satellites capable of transmitting disaster information, and users capable of receiving disaster information. Thorough legal reviews must be accomplished to determine the consequences existing patents have on DNMS implementation.

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IV. GPS POLICY

The GPS has become a ubiquitous utility; with each added capability, feature or upgrade and with increasing infrastructure dependence, the system and all space capabilities have become inherently intertwined in policy and lawmaking decisions and strategies from the national and international level, down to United States military operations. The DNMS augmentation to the GPS must abide by existing policy, and as currently theorized, does.

The National Security Strategy (NSS) signed by President Barack Obama in May 2010 highlights the need to continue growth of indigenous space capabilities, and to continue investing in the research and development of next-generation technologies and capabilities to benefit commercial, civil and other communities to maintain the viability of space for future generations. Additionally, the strategy declares that the space domain is a shared area that exists outside exclusive national jurisdictions and is "…the connective tissue around our globe upon which all nations' security and prosperity depend" (Obama, 2010). The DNMS would be, like GPS, a connective tissue of which all nations depend upon and prosper from.

The GPS is guided by the National Security Presidential Directive #39, December 2004, as well in which then President George Bush acknowledges the criticality of GPS on multiple sectors of the U.S. infrastructure. President Bush also directed that PNT infrastructure be modernized to deploy new public safety services when required, and to the maximum extent practical (Obama, 2004). The DNMS would not interfere with the existing or future planned PNT data used by critical infrastructures, and would in fact add public safety services fostering international cooperation and goodwill.

The NSS Space supplement, the National Security Space Strategy, released by then Secretary of Defense Robert Gates in January 2011, also highlights that space is vital in order to enable the viability of the global economy. The DNMS would have the ability to spark worldwide manufacturing of localized GPS enabled devices, in addition to those already being incorporated into existing devices manufactured throughout the world. Additionally, Robert Gates said: “We will explore sharing space-derived information as ‘global utilities’ with partnered nations. As we do today with the positioning, navigation, and timing services of the Global Positioning System, we will provide services derived from selected space systems and enhance those services through partnerships [with other responsible nations]” (Gates, 2011). An opportunity exists for collaboration and partnership with other nations not yet seen.

The National Space Policy of June 2010 has a stated goal to: “Expand international cooperation on mutually beneficial space activities to broaden and extend the benefits of space [and] further the peaceful use of space …” (Obama, 2010). The U.S. will enable others to share the benefits provided by the use of space; in that, the DNMS excels.

Being operated by the Department of Defense, the GPS is also inherently guided by defense strategy. In the National Defense Strategy, signed in June 2008 by then Secretary of Defense Robert Gates, it is acknowledged that “…global prosperity is contingent on the free flow of ideas, goods, and services” (Gates, 2008). The National Military Strategy also supports the DNMS in that all domains (air, space, cyberspace, etc) allow for high-speed, high-volume exchange of ideas, information and capital, among other things, that are critical to the global economy (Mullen, 2011).

The Department of Defense Directive 4650.05, signed February 2008 which guides Position Navigation and Timing does not explicitly support an augmentation such as DNMS, but the guidance is specific to PNT information, not the GPS as an all-encompassing entity and the DNMS does not interfere with the PNT guidance outlined within the DoDD, or adversely affect GPS operations (England 2008

V. CONCLUSIONS

The GPS has potential as an effective communication link to add critical capacity and reach to global disaster notification broadcast systems. This GPS augmentation system can be tied to other worldwide disaster aggregation and reporting systems and organizations with minimal costs, and be provided as a free utility without affecting the ability and capacity to continue providing PNT data. As an added data link, this system could remove many obstacles to reaching those affected by disasters, such as cell phone carriers, numerous other data links, delays, geographic reach, economic viability, et al.

Adequate bandwidth capacity exists in the planned L5 SoL GPS signal to provide notifications for the more than 200 million individuals currently affected by disasters annually, given some limitations and assumptions regarding notification trigger criteria. Some limitations in this GPS augmentation exist in overall system capacity and timeliness. Not every disaster where an individual is killed can be reported while still maintaining capacity such that the PNT data resident in the GPS signal remains unaffected. Similarly, given the existing control segment infrastructure and the notification timelines of some natural disaster events such as earthquakes or tsunamis, limitations exist in the system's overall effectiveness. The system as designed however meets the requirements outlined in section III.A, and has potential to provide notifications for the vast majority of disaster events and affected individuals.

For this system to be realized, the United States must accept ownership as well as implementation and service costs. National level policy through military strategy must account for the role and associated responsibilities the United States would accept by introducing such a system. Ultimately, through relatively minimal costs, the United States could provide additional capacity to worldwide disaster notification services saving many lives. Additionally, international partnerships, cooperation and prosperity would be fostered, while furthering the peaceful uses of space.

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VI. RECOMMENDED AREAS OF FURTHER STUDY

Augmenting the GPS to provide disaster notification services offers new capability; however, throughout this analysis many assumptions were made and many areas exist which require further study before final DNMS design decisions can be made.

More refined natural disaster epidemiology data needs to be analyzed in order to more accurately drive worldwide notification system requirements; specifically, geographic size, dispersion and statistical distribution need to be refined in order to ensure adequate system capacity and capability.

ICDs currently exist for all planned future GPS signals; however implementation plans are extremely limited in the control, space and user GPS segments. Accurate control segment specifics such as system automation, processing capacity, and communication timeliness; space segment specifics such as data processing, memory, broadcast message timelines, and satellite cross-linking capabilities; and user segment specifics such as all-in-view data processing, 'cold-start' signal tracking timeliness, and many others for all segments remain largely unknown. For all GPS segments and for all modernized GPS signals, phased implementation plans are needed.

A detailed software simulation of the ad-hoc satellite tasking transmission scheme mentioned as option 2 in paragraph III.C.2 needs to be pursued. This transmission method has potential to increase available bandwidth of the DNMS system, though it adds real-time planning and computational complexity.

All areas of additional design considerations need to be refined. The performance of the L5 signal and its 'protected' nature against inadvertent, intentional white and spoofed interference must be tested in laboratory and real world with ground and airborne assets. The WAAS consideration of DNMS through commercially leased GEO SATCOM needs to be further explored and refined as well, as it offers many significant advantages to the implementation of DNMS. Additionally, thorough legal reviews of governmental implementation of corporate patents must be accomplished.

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